Texas A&M Transportation Institute
Proving Ground

Test Report No. 440592

DEVELOP GUIDELINES FOR INSPECTION, REPAIR, AND USE OF PORTABLE CONCRETE BARRIERS—VOLUME 2: CRASH REPORT

COOPERATIVE RESEARCH PROGRAM

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16. Abstract

The purpose of the tests reported herein was to assess the performance of the damaged portable concrete barrier according to the safety-performance evaluation guidelines included in the American Association of State Highway and Transportation Officials *Manual for Assessing Safety Hardware* (*MASH*), Second Edition. The crash tests were performed in accordance with *MASH* Test 3-11, which involves a 2270P vehicle weighing 5000 lb impacting the longitudinal barrier while traveling at 62 mi/h and 25 degrees.

This report provides details on the damaged portable concrete barriers, the crash tests and results, and the performance assessment of the damaged portable concrete barriers for *MASH* Test Level 3 (TL-3) longitudinal barrier evaluation criteria.

The damaged portable concrete barriers met the performance criteria for *MASH* TL-3 longitudinal barriers.

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DISCLAIMER

This research was sponsored by the Texas Department of Transportation (TxDOT) and the Federal Highway Administration (FHWA). The contents of this report reflect the views of the authors, who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official view or policies of FHWA or TxDOT. This report does not constitute a standard, specification, or regulation.

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The results of the crash testing reported herein apply only to the article tested.

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SI* (MODERN METRIC) CONVERSION FACTORS				
APPROXIMATE CONVERSIONS TO SI UNITS				
Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in2	square inches	645.2	square millimeters	mm2
ft2	square feet	0.093	square meters	m2
yd2	square yards	0.836	square meters	m2
ac	acres	0.405	hectares	ha
mi2	square miles	2.59	square kilometers	km2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft3	cubic feet	0.028	cubic meters	m3
yd3	cubic yards	0.765	cubic meters	m3
	NOTE: volumes greater than 1000L shall be shown in m3			
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or metric ton")	Mg (or "t")
		TEMPERATURE (exact degrees)		
°F	Fahrenheit	5(F-32)/9 or (F-32)/1.8	Celsius	°C
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in2	poundforce per square inch	6.89	kilopascals	kPa
APPROXIMATE CONVERSIONS FROM SI UNITS				
Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm2	square millimeters	0.0016	square inches	in2
m2	square meters	10.764	square feet	ft2
m2	square meters	1.195	square yards	yd2
ha	hectares	2.47	acres	ac
km2	Square kilometers	0.386	square miles	mi2
		VOLUME		
mL	milliliters	0.034	fluid ounces	oz
L	liters	0.264	gallons	gal
m3	cubic meters	35.314	cubic feet	ft3
m3	cubic meters	1.307	cubic yards	yd3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000lb)	T
		TEMPERATURE (exact degrees)		
°C	Celsius	1.8C+32	Fahrenheit	°F
		FORCE and PRESSURE or STRESS		
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lb/in2

*SI is the symbol for the International System of Units

Chapter 1. INTRODUCTION

The purpose of the tests reported herein was to assess the performance of Texas Department of Transportation (TxDOT) damaged portable concrete barriers according to the safety-performance evaluation guidelines included in the American Association of State Highway and Transportation Officials (AASHTO) *Manual for Assessing Safety Hardware* (*MASH*), Second Edition (*1*). The crash tests were performed in accordance with *MASH* Test 3-11.

Chapter 2. SYSTEM DETAILS

2.1. TEST ARTICLE AND INSTALLATION DETAILS

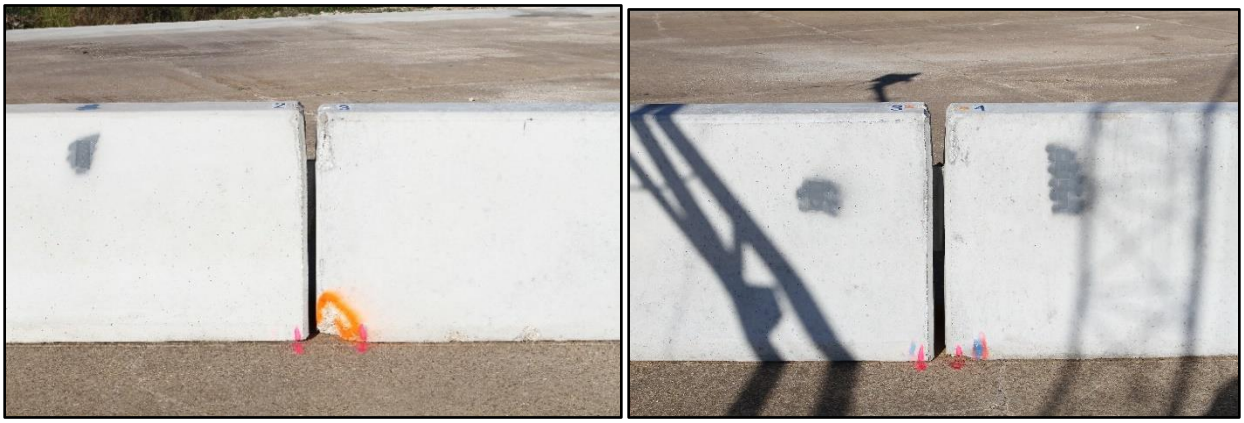
Each installation consisted of seven 30-ft long, 32-inch tall, F-shape barriers connected end to end with JJ hook connections, for a total length of 210 ft 6 inches. For both tests, the barrier segments were specifically selected based on their existing damage modes, which included concrete spalling, concrete cracks, and segment connection deformations.

For the first test (440592-1), Barrier 3 was selected due to a large 6-mm wide crack located on the field side of the installation that ran vertically 246 inches downstream from the joint of barriers 2 and 3. The downstream JJ hook on barrier 2 was bent 8 degrees. The upstream JJ hook on barrier 3 was not damaged, and the downstream JJ hook was bent 12 degrees. The upstream JJ hook on barrier 4 was not damaged.

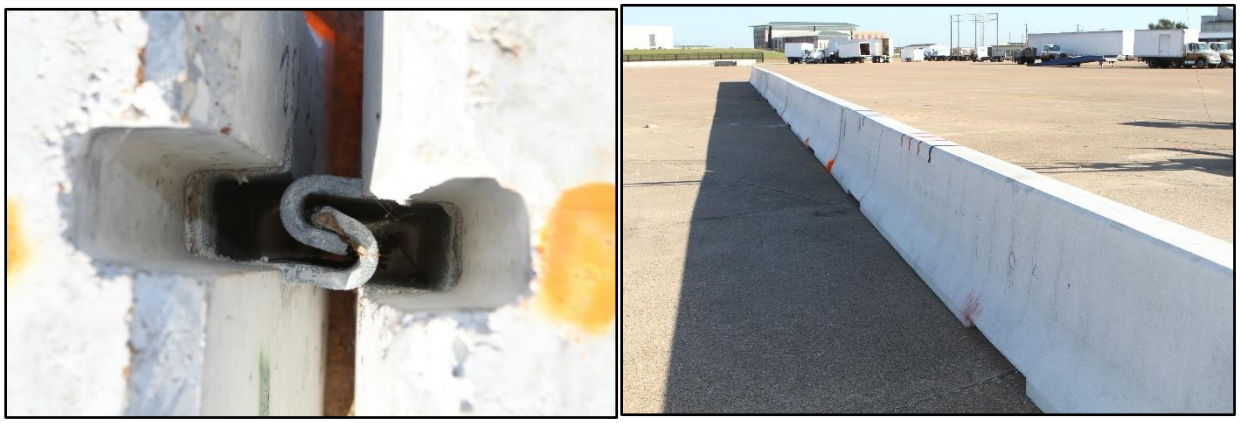
For the second test (440592-2), spalling was manufactured by Texas A&M Transportation Institute (TTI) personnel on the traffic side toe of barriers 3 and 4 at their joint. Each had a spall measuring approximately 3¾ inches wide × 13 inches high × 2 inches deep. At the same joint on the field side, the toe of barrier 4 was intentionally spalled and measured approximately 24 inches wide × 5 inches high × 2 inches deep. The JJ hooks at the joint of barriers 2 and 3 were not damaged. The downstream JJ hook on barrier 3 was bent 19 degrees, and the upstream JJ hook of barrier 4 was bent 15 degrees.

Figure 2.1 and Figure 2.2 show pictures of the F-shape barriers before testing. Figure 2.3 shows a drawing of the test layout. Appendix A provides further details on the damaged portable concrete barriers. Drawings were provided by the TTI Proving Ground, and construction was performed by TTI Proving Ground personnel.

(a) (b)

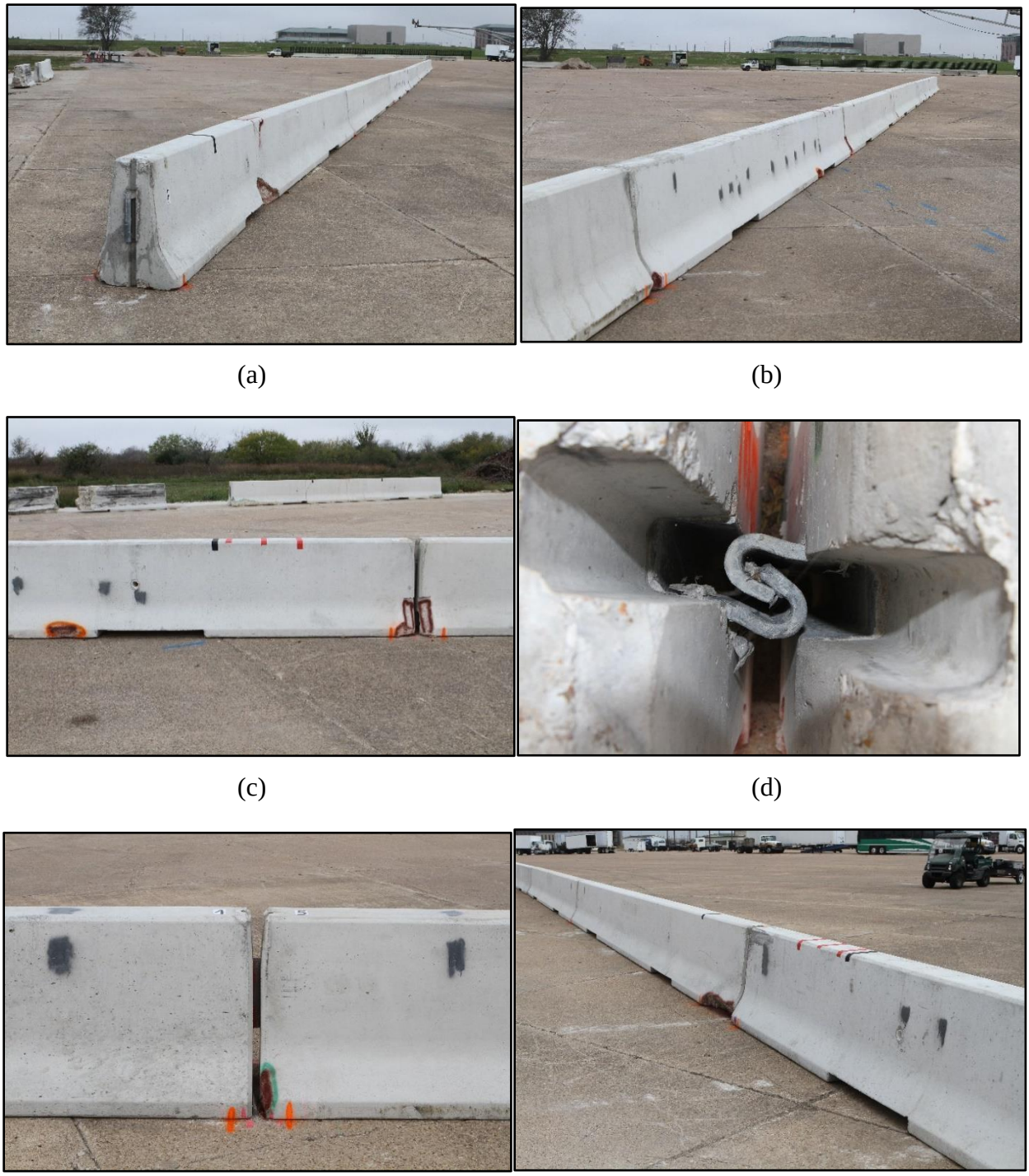


(c) (d)



(e) (f)

Figure 2.1. Damaged Portable Concrete Barriers prior to Test No. 440592-1.



(a) (b)

(c) (d)

(e) (f)

Figure 2.2. Damaged Portable Concrete Barriers prior to Test No. 440592-2.

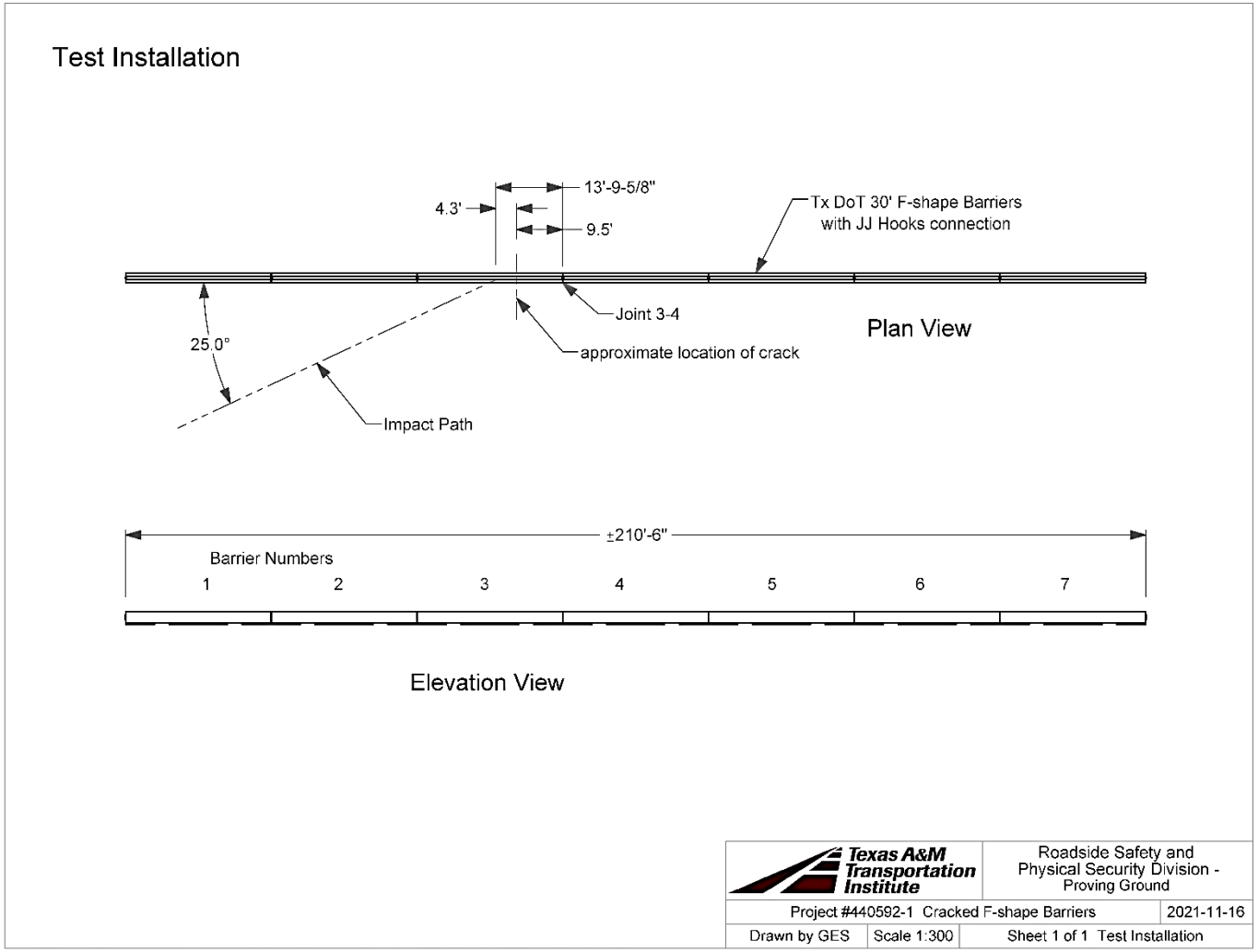


Figure 2.3. Details on Damaged Portable Concrete Barriers.

2.2. DESIGN MODIFICATIONS DURING TESTS

No modifications were made to the installation during the testing phase.

2.3. MATERIAL SPECIFICATIONS

Appendix B provides material documents for the materials used to install/construct the damaged portable concrete barriers. Table 2.1 shows the average compressive strengths of the concrete.

Table 2.1. Concrete Strength.

Location	Design Strength (psi)	Avg. Strength (psi)	Detailed Location
Barrier 3[a]	3600	7270	Core taken from barrier 3 after test 440592-1
Barrier 4	3600	8210	Core taken from barrier 4 after test 440592-1
Barrier 3[a]	3600	5740	Core taken from barrier 3 after test 440592-2

[a] These were not the same barrier; they were the barriers labeled barrier 3 for each respective test.

Chapter 3. TEST REQUIREMENTS AND EVALUATION CRITERIA

3.1. CRASH TEST PERFORMED/MATRIX

Table 3.1 shows the test conditions and evaluation criteria for *MASH* Test Level 3 (TL-3) for longitudinal barriers. The target critical impact points (CIPs) for each test were determined using the information provided in *MASH* Section 2.2.1 and Section 2.3.2. Figure 3.1 and Figure 3.2 show the target CIP for *MASH* Test 3-11 on the damaged portable concrete barriers.

Table 3.1. Test Conditions and Evaluation Criteria Specified for *MASH* TL-3 Longitudinal Barriers.

Test Designation	Test Vehicle	Impact Speed	Impact Angle	Evaluation Criteria
3-11	2270P	62 mi/h	25°	A, D, F, H, I

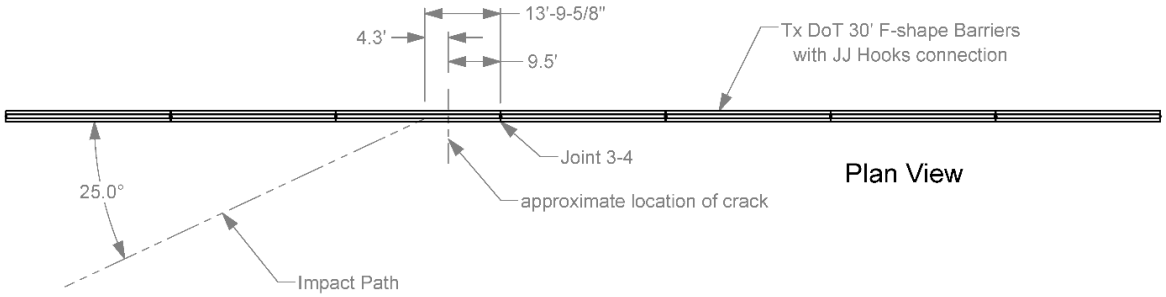


Figure 3.1. Target CIP for *MASH* TL-3 Test No. 440592-1 on Damaged Portable Concrete Barriers.

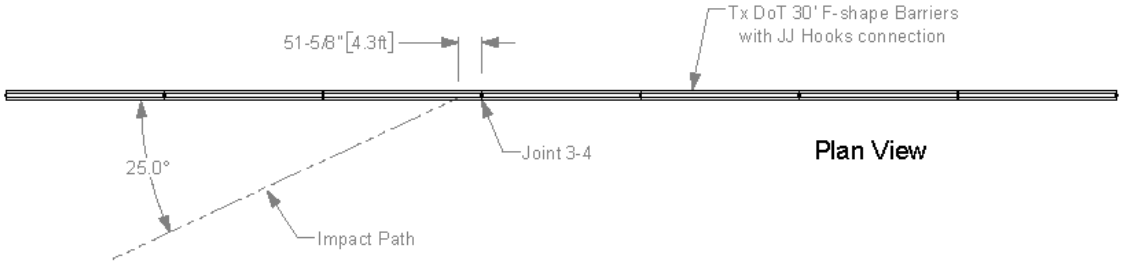


Figure 3.2. Target CIP for *MASH* TL-3 Test No. 440592-2 on Damaged Portable Concrete Barriers.

The crash tests and data analysis procedures were in accordance with guidelines presented in *MASH*. Chapter 4 presents brief descriptions of these procedures.

3.2. EVALUATION CRITERIA

The appropriate safety evaluation criteria from Tables 2.2 and 5.1 of *MASH* were used to evaluate the crash tests reported herein. Table 3.2 provides detailed information on the evaluation criteria.

Table 3.2. Evaluation Criteria Required for *MASH* Testing.

Evaluation Factors	**Evaluation Criteria**		***MASH* Test**
Structural Adequacy	A.	Test article should contain and redirect the vehicle or bring the vehicle to a controlled stop; the vehicle should not penetrate, underride, or override the installation although controlled lateral deflection of the test article is acceptable.	11
Occupant Risk	D.	Detached elements, fragments, or other debris from the test article should not penetrate or show potential for penetrating the occupant compartment, or present undue hazard to other traffic, pedestrians, or personnel in a work zone. Deformations of, or intrusions into, the occupant compartment should not exceed limits set forth in Section 5.2.2 and Appendix E of *MASH*.	11
	F.	The vehicle should remain upright during and after collision. The maximum roll and pitch angles are not to exceed 75 degrees.	11
	H.	Occupant impact velocities (OIV) should satisfy the following limits: Preferred value of 30 ft/s, or maximum allowable value of 40 ft/s. Occupant impact velocities (OIV) should satisfy the following limits: Preferred value of 10 ft/s, or maximum allowable value of 16 ft/s.	11
	I.	The occupant ridedown accelerations should satisfy the following: Preferred value of 15.0 g, or maximum allowable value of 20.49 g.	11

Chapter 4. TEST CONDITIONS

4.1. TEST FACILITY

The full-scale crash tests reported herein were performed at the TTI Proving Ground, an International Standards Organization (ISO)/International Electrotechnical Commission (IEC) 17025-accredited laboratory with American Association for Laboratory Accreditation (A2LA) Mechanical Testing Certificate 2821.01. The full-scale crash tests were performed according to TTI Proving Ground quality procedures, as well as *MASH* guidelines and standards.

The test facilities of the TTI Proving Ground are located on The Texas A&M University System RELLIS Campus, which consists of a 2000-acre complex of research and training facilities situated 10 mi northwest of the flagship campus of Texas A&M University. The site, formerly a United States Army Air Corps base, has large expanses of concrete runways and parking aprons well suited for experimental research and testing in the areas of vehicle performance and handling, vehicle-roadway interaction, highway pavement durability and efficacy, and roadside safety hardware and perimeter protective device evaluation. The sites selected for construction and testing are along the edge of an out-of-service apron/runway. The apron/runway consists of an unreinforced jointed-concrete pavement in 12.5-ft × 15-ft blocks nominally 6 inches deep. The aprons were built in 1942, and the joints have some displacement but are otherwise flat and level.

4.2. VEHICLE TOW AND GUIDANCE SYSTEM

For the testing utilizing the 2270P vehicles, each vehicle was towed into the test installation using a steel cable guidance and reverse tow system. A steel cable for guiding the test vehicle was tensioned along the path, anchored at each end, and threaded through an attachment to the front wheel of the test vehicle. An additional steel cable was connected to the test vehicle, passed around a pulley near the impact point and through a pulley on the tow vehicle, and then anchored to the ground such that the tow vehicle moved away from the test site. A 2:1 speed ratio between the test and tow vehicle existed with this system. Just prior to impact with the installation, the test vehicle was released and ran unrestrained. The vehicle remained freewheeling (i.e., no steering or braking inputs) until it cleared the immediate area of the test site.

4.3. DATA ACQUISITION SYSTEMS

4.3.1. Vehicle Instrumentation and Data Processing

Each test vehicle was instrumented with a self-contained onboard data acquisition system. The signal conditioning and acquisition system is a 16-channel Tiny Data Acquisition System (TDAS) Pro produced by Diversified Technical Systems Inc. The accelerometers, which measure the x, y, and z axis of vehicle acceleration, are strain gauge type with linear millivolt output proportional to acceleration. Angular rate sensors, measuring vehicle roll, pitch, and yaw rates, are ultra-small, solid-state units designed for crash test service. The TDAS Pro hardware and software conform to the latest SAE J211, Instrumentation for Impact Test. Each of the

16 channels is capable of providing precision amplification, scaling, and filtering based on transducer specifications and calibrations. During the test, data are recorded from each channel at a rate of 10,000 samples per second with a resolution of one part in 65,536. Once data are recorded, internal batteries back these up inside the unit in case the primary battery cable is severed. Initial contact of the pressure switch on the vehicle bumper provides a time zero mark and initiates the recording process. After each test, the data are downloaded from the TDAS Pro unit into a laptop computer at the test site. The Test Risk Assessment Program (TRAP) software then processes the raw data to produce detailed reports of the test results.

Each of the TDAS Pro units is returned to the factory annually for complete recalibration and to ensure that all instrumentation used in the vehicle conforms to the specifications outlined by SAE J211. All accelerometers are calibrated annually by means of an ENDEVCO™ 2901 precision primary vibration standard. This standard and its support instruments are checked annually and receive a National Institute of Standards Technology (NIST) traceable calibration. The rate transducers used in the data acquisition system receive calibration via a Genisco Rate-of-Turn table. The subsystems of each data channel are also evaluated annually, using instruments with current NIST traceability, and the results are factored into the accuracy of the total data channel per SAE J211. Calibrations and evaluations are also made anytime data are suspect. Acceleration data are measured with an expanded uncertainty of ±1.7 percent at a confidence factor of 95 percent (k = 2).

TRAP uses the data from the TDAS Pro to compute the occupant/compartment impact velocities, time of occupant/compartment impact after vehicle impact, and highest 10-millisecond (ms) average ridedown acceleration (RA). TRAP calculates change in vehicle velocity at the end of a given impulse period. In addition, maximum average accelerations over 50-ms intervals in each of the three directions are computed. For reporting purposes, the data from the vehicle-mounted accelerometers are filtered with an SAE Class 180-Hz low-pass digital filter, and acceleration versus time curves for the longitudinal, lateral, and vertical directions are plotted using TRAP.

TRAP uses the data from the yaw, pitch, and roll rate transducers to compute angular displacement in degrees at 0.0001-s intervals, and then plots yaw, pitch, and roll versus time. These displacements are in reference to the vehicle-fixed coordinate system, with the initial position and orientation being initial impact. Rate of rotation data are measured with an expanded uncertainty of ±0.7 percent at a confidence factor of 95 percent (k = 2).

4.3.2. Anthropomorphic Dummy Instrumentation

According to *MASH*, use of a dummy in the 2270P vehicle is optional, and no dummy was used in the tests.

4.3.3. Photographic Instrumentation Data Processing

Photographic coverage of each test included three digital high-speed cameras:

- One overhead with a field of view perpendicular to the ground and directly over the impact point.

- One placed upstream from the installation at an angle to have a field of view of the interaction of the rear of the vehicle with the installation.
- A third placed with a field of view parallel to and aligned with the installation at the downstream end.

A flashbulb on the impacting vehicle was activated by a pressure-sensitive tape switch to indicate the instant of contact with the damaged portable concrete barriers. The flashbulb was visible from each camera. The video files from these digital high-speed cameras were analyzed to observe phenomena occurring during the collision and to obtain time-event, displacement, and angular data. A digital camera recorded and documented conditions of each test vehicle and the installation before and after the test.

Chapter 5. *MASH* TEST 3-11 (CRASH TEST NO. 440592-1)

5.1. TEST DESIGNATION AND ACTUAL IMPACT CONDITIONS

Table 5.1 and Table 5.2 provide details on the *MASH* impact conditions for this test, and Figure 5.1 and Figure 5.2 depict the target impact setup.

Table 5.1. Impact Conditions for *MASH* 3-11, Test No. 440592-1.

Test Parameter	Specification	Tolerance	Measured
Impact Speed (mi/h)	62	±2.5 mi/h	61.8
Impact Angle (deg)	25	±1.5°	25.2
Vehicle Inertial Weight (lb)	5000	±110 lb	5025
Impact Severity (kip-ft)	106	≥106 kip-ft	116.3
Impact Location	13.8 ft ± 1 ft upstream of the center of the joint between barriers 3 and 4	±1 ft	13.9 ft upstream of the center of the joint between barriers 3 and 4

Table 5.2. Exit Parameters for *MASH* 3-11, Test No. 440592-1.

Exit Parameter	Measured
Speed (mi/h)	53.3
Trajectory (deg)	7
Heading (deg)	18
Brakes applied post impact (s)	Brakes not applied
Vehicle at rest position	203 ft downstream of impact point 10 ft to the field side 85° left
Comments:	Vehicle remained upright and stable. Vehicle crossed exit box 77 ft downstream from loss of contact. Not less than 32.8 ft downstream from loss of contact for cars and pickups is optimal.

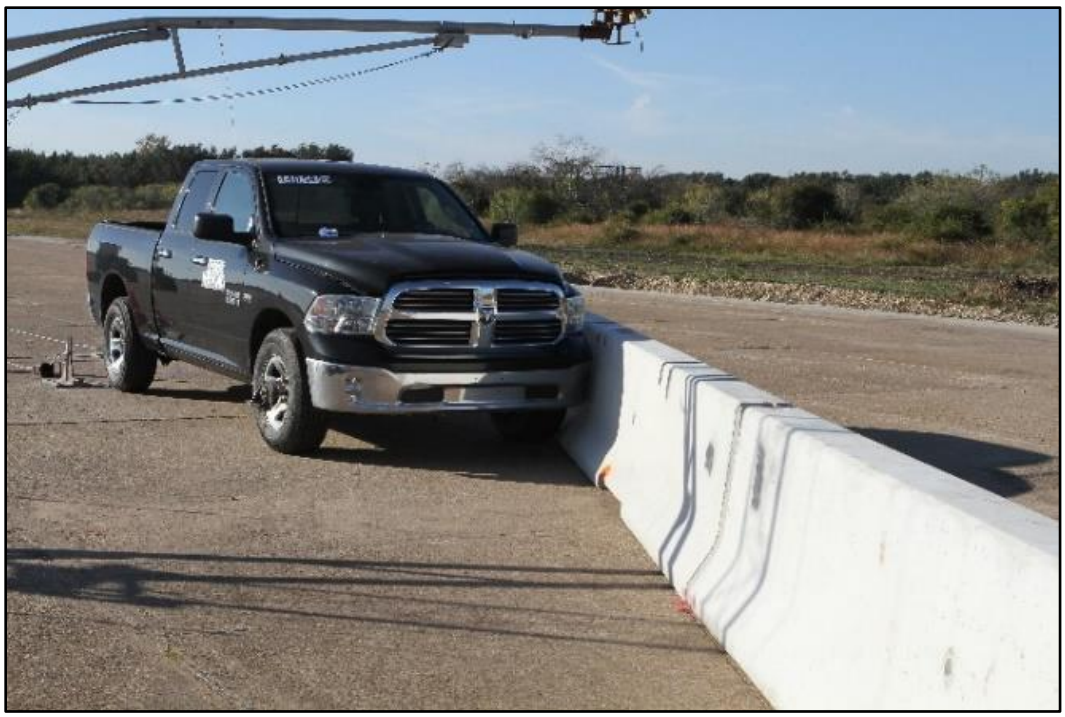


Figure 5.1. Damaged Portable Concrete Barriers/Test Vehicle Geometrics for Test No. 440592-1, Front View.

Figure 5.2. Damaged Portable Concrete Barriers/Test Vehicle Geometrics for Test No. 440592-1, Rear View.

5.2. WEATHER CONDITIONS

Table 5.3 provides the weather conditions for Test No. 440592-1

Table 5.3. Weather Conditions for Test No. 440592-1.

Date of Test	December 1, 2021 AM
Temperature (°F)	67
Relative Humidity (%)	88
Wind Direction (deg)	175
Vehicle Traveling (deg)	350
Wind Speed (mi/h)	4

5.3. TEST VEHICLE

Figure 5.3 and Figure 5.4 show the 2016 RAM 1500 used for the crash test. Table 5.4 shows the vehicle measurements. Figure C.1 in Appendix C.1 gives additional dimensions and information on the vehicle.

Figure 5.3. Test Vehicle before Test No. 440592-1, Front View.

Figure 5.4. Test Vehicle before Test No. 440592-1, Front View Close-Up.

Table 5.4. Vehicle Measurements for Test No. 440592-1.

Test Parameter	*MASH*	Allowed Tolerance	Measured
Dummy (if applicable)[a] (lb)	165	N/A	N/A
Curb Weight (lb)	5000	N/A	5083
Gross Static[a] (lb)	5000	±110	5025
Wheelbase (inches)	148	±12	140.5
Front Overhang (inches)	39	±3	40
Overall Length (inches)	237	±13	227.5
Overall Width (inches)	78	±2	78.5
Hood Height (inches)	43	±4	46
Track Width[b] (inches)	67	±1.5	68.3
CG aft of Front Axle[c] (inches)	63	±4	59.6
CG above Ground[c,d] (inches)	28	≥28	28.6

Note: N/A = not applicable.
[a] If a dummy is used, the gross static vehicle mass should be increased by the mass of the dummy.
[b] Average of front and rear axles.
[c] For test inertial mass.
[d] 2270P vehicle must meet minimum center of gravity (CG) height requirement.

5.4. TEST DESCRIPTION

Table 5.5 lists events that occurred during Test No. 440592-1. Figures C.4 and C.5 in Appendix C.2 present sequential photographs during the test.

Table 5.5. Events during Test No. 440592-1.

Time (s)	Events
0.0000	Vehicle impacts the installation
0.0413	Upstream end of barrier 3 begins to lift
0.0430	Vehicle begins to redirect
0.0475	Large preexisting crack on backside of barrier begins to expand
0.0810	Front passenger side tire lifts off pavement
0.1090	Rear passenger side tire lifts off pavement
0.1940	Vehicle travels parallel with installation
0.4150	Vehicle loses contact with the barrier
0.5540	Front driver side tire makes contact with pavement
0.8690	Front passenger side tire makes contact with pavement

5.5. DAMAGE TO TEST INSTALLATION

Major cracking and spalling were observed at the downstream scupper of barrier 3. There was a significant amount of exposed rebar, which was severed by the impact of the test vehicle. The existing cracks before impact ranged in size from 0.1 mm to 6 mm, and post impact, they were between 0.1 mm and 108 mm. The main crack of concern, which was located on the field side of the third barrier 246 inches downstream from the joint of barriers 2 and 3, widened from 6 mm to 108 mm, and a secondary crack extending from the main crack widened from 2.5 mm to 102 mm. The JJ hook on the downstream end of barrier 2 bent 2 degrees, and the JJ hook on the upstream end of barrier 3 bent 13 degrees. The JJ hook on the downstream end of barrier 3 bent 3 degrees, and the JJ hook on the upstream end of barrier 4 bent 34 degrees.

Figure 5.5 shows images of the damage to the test article. Table 5.6 and Table 5.7 list the barrier movement and the damage caused, respectively.

(a)

(b)

Figure 5.5. Damaged Portable Concrete Barriers after Test No. 440592-1.

(c)

(d)

Figure 5.5. Damaged Portable Concrete Barriers after Test No. 440592-1 (Continued).

Table 5.6. Barrier Movement of Damaged Portable Concrete Barrier, Test No. 440592-1.

Joint/Barrier	Movement D/S (inches)	Movement U/S (inches)	Movement T/S (inches)	Movement F/S (inches)	Comments
1	7	—	—	2	—
1/2	$6^1/_2$	—	3	—	—
2/3	7	—	—	7	—
3/4	—	—	—	59	Barrier 3 was lifted 4½ inches
4/5	—	4	$3^1/_2$	—	—
5/6	—	$^3/_4$	—	1	—
6/7	—	1	—	—	—
7	—	$^1/_2$	—	1	—

Note: D/S = Downstream, U/S = Upstream, T/S = Traffic Side, F/S = Field Side. A dash indicates "none."

Table 5.7. Damage to Damaged Portable Concrete Barrier, Test No. 440592-1.

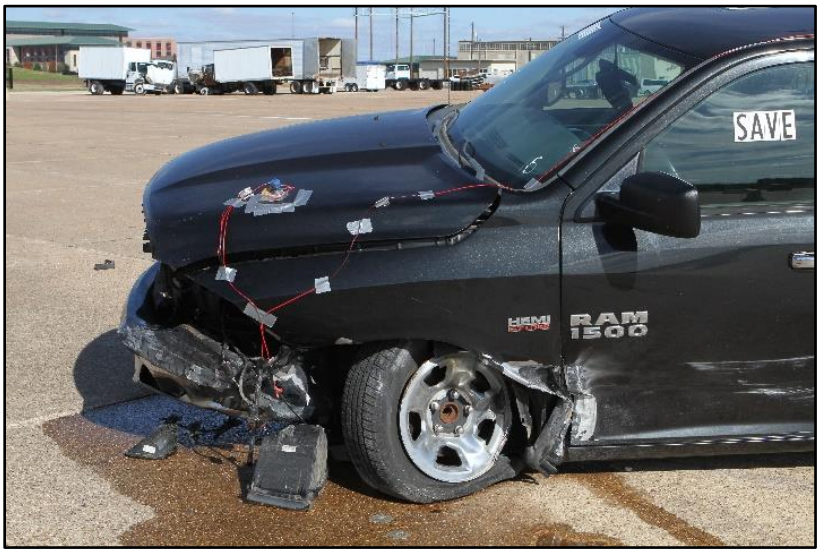
Test Parameter	**Measured**
Permanent Deflection/Location	61 inches toward field side, 100.5 inches upstream from the joint of barriers 3 and 4
Dynamic Deflection	61 inches toward field side
Working Width[a] and Height	85 inches, at a height of 3 inches

[a] Per *MASH*, "The working width is the maximum dynamic lateral position of any major part of the system or vehicle. These measurements are all relative to the pre-impact traffic face of the test article." In other words, working width is the total barrier width plus the maximum dynamic intrusion of any portion of the barrier or test vehicle past the field side edge of the barrier.

5.6. DAMAGE TO TEST VEHICLE

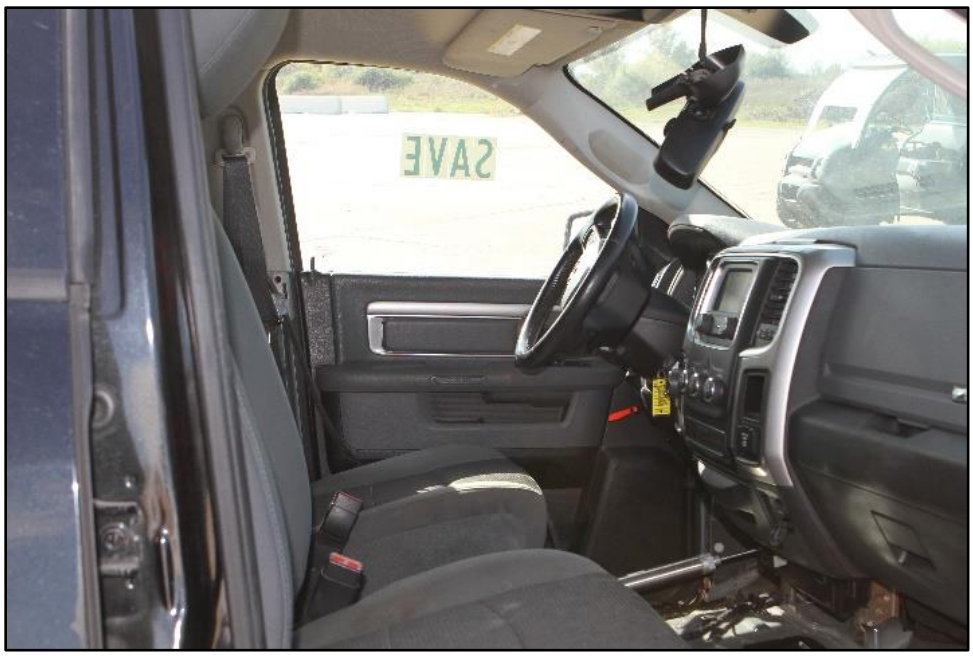
Figures C.2 and C.3 in Appendix C.1 provide exterior crush and occupant compartment measurements. Figure 5.6 shows damage to the test vehicle exterior, and Figure 5.7 shows damage inside the test vehicle. Table 5.8 lists the occupant compartment intrusion measurements, and Table 5.9 lists damage to the vehicle.

(a)



(b)

Figure 5.6. Test Vehicle after Test No. 440592-1.



(a)

(b)

Figure 5.7. Interior of Test Vehicle after Test No. 440592-1.

Table 5.8. Occupant Compartment Deformation, Test No. 440592-1.

Test Parameter	Specification	Measured
Roof	≤4.0 inches	0 inches
Windshield	≤3.0 inches	0 inches
A and B Pillars	≤5.0 overall/≤3.0 inches lateral	0 inches
Foot Well/Toe Pan	≤9.0 inches	0 inches
Floor Pan/Transmission Tunnel	≤12.0 inches	0 inches
Side Front Panel	≤12.0 inches	1 inch
Front Door (above Seat)	≤9.0 inches	0 inches
Front Door (below Seat)	≤12.0 inches	1 inch

Table 5.9. Damage to Vehicle, Test No. 440592-1.

Side Windows	Side windows remained intact
Maximum Exterior Deformation	12 inches in the left plane at the front corner at bumper height
VDS	11LFQ5
CDC	11FLEW3
Fuel Tank Damage	None
Description of Damage to Vehicle:	The front bumper, hood, grill, left headlight, left front fender, left front tire and rim, left front door, left rear door, left cab corner, left rear quarter fender, left rear tire and rim, left taillight, tailgate, and rear bumper were damaged.

5.7. OCCUPANT RISK FACTORS

Data from the accelerometers were digitized for evaluation of occupant risk, and the results are shown in Table 5.10. Figure C.6 in Appendix C.3 shows the vehicle angular displacements, and Figures C.7 through C.9 in Appendix C.4 show acceleration versus time traces.

Table 5.10. Occupant Risk Factors for Test No. 440592-1.

Test Parameter	*MASH*	Measured	Time
OIV, Longitudinal (ft/s)	≤40.0	12.3	0.0983 s on left side of interior
OIV, Lateral (ft/s)	≤40.0	21.5	0.0983 s on left side of interior
Ridedown, Longitudinal (g)	≤20.49	5.0	0.1262–0.1362 s
Ridedown, Lateral (g)	≤20.49	12.6	0.2338–0.2438 s
Theoretical Head Impact Velocity (THIV) (m/s)	N/A	7.7	0.0953 s on left side of interior
Acceleration Severity Index (ASI)	N/A	1.6	0.0528–0.1028 s
50-ms MA Longitudinal (g)	N/A	−6.6	0.0141–0.0641 s
50-ms MA Lateral (g)	N/A	11.8	0.0276–0.0776 s
50-ms MA Vertical (g)	N/A	−3.8	1.0732–1.1232 s
Roll (deg)	≤75	17	0.6751 s
Pitch (deg)	≤75	16	0.6976 s
Yaw (deg)	N/A	61	1.0994 s

5.8. TEST SUMMARY

Table 5.11, Table 5.12, Figure 5.8, Figure 5.9, and Figure 5.10 summarize the results for Test No. 440592-1.

Table 5.11. Summary of Results for Test No. 440592-1, General Information, Impact and Exit Conditions.

General Information	Test Agency	Texas A&M Transportation Institute
	Test Standard Test No.	*MASH* Test 3-11
	TTI Test No.	440592-1
	Test Date	2021-12-01
Test Article	Type	Portable Concrete Barrier
	Name	Damaged Portable Concrete Barrier
	Installation Length	210 ft, 6 inches
	Material or Key Elements	Seven F-Shaped Concrete Barriers
	Foundation Type/Condition	Concrete Apron, Dry
Test Vehicle	Type/Designation	2270P
	Make and Model	2016, RAM 1500
	Curb	5083 lb
	Test Inertial	5025 lb
	Dummy	N/A
	Gross Static	5025 lb
Impact Conditions	Speed	61.8 mi/h
	Angle	25.2 degrees
	Location	13.9 ft upstream from the centerline of the joint between barrier 3 and 4
	Impact Severity	116.3 kip-ft
Exit Conditions	Speed	53.3 mi/h
	Exit Trajectory/Heading	7 degrees/18 degrees

Table 5.12. Summary of Results for Test No. 440592-1, Occupant Risk, Vehicle and Test Article Damage.

Occupant Risk Values	Longitudinal OIV	12.3 ft/s
	Lateral OIV	21.5 ft/s
	Longitudinal RDA	5.0 g
	Lateral RDA	12.6 g
	THIV	7.7 m/s
	ASI	1.6
Max. 0.050-s Average	Longitudinal	−6.6 g
	Lateral	11.8 g
	Vertical	−3.8 g
Post-Impact Trajectory	Stopping Distance	203 ft downstream, 10 ft on field side
Vehicle Stability	Maximum Roll Angle	17°
	Maximum Pitch Angle	16°
	Maximum Yaw Angle	61°
	Vehicle Snagging	No indication of snagging
	Vehicle Pocketing	No indication of pocketing
Test Article Deflections	Dynamic	61 inches
	Permanent	61 inches
	Working Width	85 inches
	Height of Working Width	3 inches
Vehicle Damage	VDS	11LFQ5
	CDC	11FLEW3
	Max. Exterior Deformation	12 inches at left front bumper
	Max. Occupant Compartment Deformation	1 inch at left kick panel area, and 1 inch at lower left front door

(a) 0.000 s

(b) 0.100 s

Figure 5.8. Summary of Results for Test No. 440592-1, Sequential Test Pictures.

(c) 0.200 s

(d) 0.300 s

Figure 5.8. Summary of Results for Test No. 440592-1, Sequential Test Pictures (Continued).

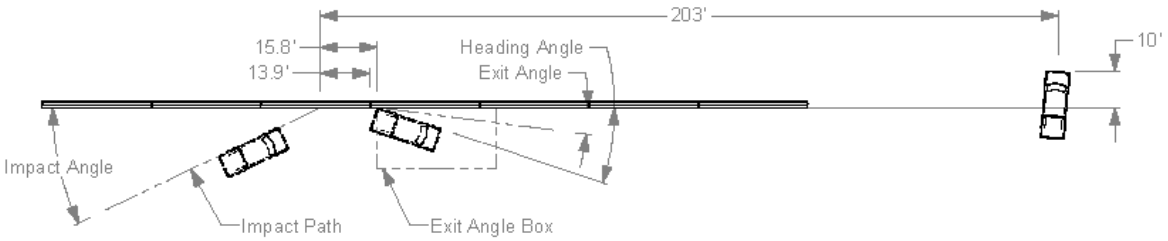


Figure 5.9. Summary of Results for Test No. 440592-1, Summary Drawing.

0.000 s

0.100 s

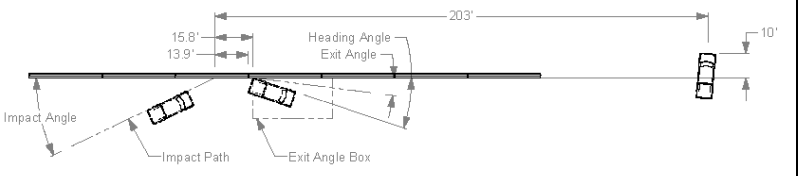
0.200 s

0.300 s

Test Agency	Texas A&M Transportation Institute (TTI)
Test Standard/Test No.	*MASH* 2016, Test 3-11
TTI Project No.	440592-1
Test Date	2021-12-01
TEST ARTICLE	
Type	Portable Concrete Barrier
Name	Damaged Portable Concrete Barrier
Length	210 ft 6 inches
Key Materials	7 F-Shaped Concrete Barriers
Soil Type and Condition	Concrete Apron, Dry
TEST VEHICLE	
Type/Designation	2270P
Year, Make and Model	2016 RAM 1500
Curb Weight (lb)	5083
Inertial Weight (lb)	5025
Dummy (lb)	N/A
Gross Static (lb)	5025
IMPACT CONDITIONS	
Impact Speed (mi/h)	61.8
Impact Angle (deg)	25.2
Impact Location	13.9 ft upstream from the centerline of the joint between barriers 3 and 4
Impact Severity (kip-ft)	116.3
EXIT CONDITIONS	
Exit Speed (mi/h)	53.3
Trajectory/Heading Angle (deg)	7/18
Exit Box Criteria	Vehicle crossed exit box
Stopping Distance (ft)	203 ft downstream 10 ft to the field side
TEST ARTICLE DEFLECTIONS	
Dynamic (inches)	61
Permanent (inches)	61
Working Width / Height (inches)	85/3
VEHICLE DAMAGE	
VDS	11LFQ5
CDC	11FLEW3
Max. Ext. Deformation (inches)	12, Left Front Bumper
Max Occupant Compartment Deformation (inches)	1, Left Kick Panel Area; 1, Lower Left Front Door

OCCUPANT RISK VALUES

Long. OIV (ft/s)	12.3	Long. Ridedown (g)	5.0	Max 50-ms Long. (g)	−6.6	Max Roll (deg)	17
Lat. OIV (ft/s)	21.5	Lat. Ridedown (g)	12.6	Max 50-ms Lat. (g)	11.8	Max Pitch (deg)	16
THIV (m/s)	7.7	ASI	1.6	Max 50-ms Vert. (g)	−3.8	Max Yaw (deg)	61



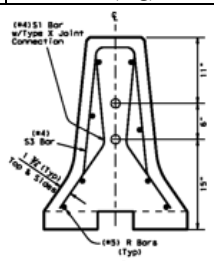


Figure 5.10. Summary of Results for *MASH* Test 3-11 on Damaged Portable Concrete Barriers, Test No. 440592-1.

Chapter 6. *MASH* TEST 3-11 (CRASH TEST NO. 440592-2)

6.1. TEST DESIGNATION AND ACTUAL IMPACT CONDITIONS

Table 6.1 and Table 6.2 provide details on the *MASH* impact conditions for this test, and Figure 6.1 and Figure 6.2 depict the target impact setup.

Table 6.1. Impact Conditions for *MASH* 3-11, Test No. 440592-2.

Test Parameter	Specification	Tolerance	Measured
Impact Speed (mi/h)	62	±2.5 mi/h	60.4
Impact Angle (deg)	25	±1.5°	24.9
Vehicle Inertial Weight (lb)	5000	±110 lb	5064
Impact Severity (kip-ft)	106	≥106 kip-ft	109.5
Impact Location	4.3 ft upstream of the center of the joint between barriers 3 and 4	±1 ft	4.3 ft upstream of the center of the joint between barriers 3 and 4

Table 6.2. Exit Parameters for *MASH* 3-11, Test No. 440592-2.

Exit Parameters	Measured
Speed (mi/h)	Out of view (not measurable)
Trajectory (deg)	Out of view (not measurable)
Heading (deg)	Out of view (not measurable)
Brakes applied post impact (s)	2.9
Vehicle at rest position	440 ft downstream of impact point 95 ft to the traffic side of the installation 30° right
Comments:	Vehicle remained upright and stable. Vehicle crossed the exit box[a] 131 ft downstream from loss of contact.

[a] Not less than 32.8 ft downstream from loss of contact for cars and pickups is optimal.

Figure 6.1. Damaged Portable Concrete Barriers/Test Vehicle Geometrics for Test No. 440592-2, Front View.

Figure 6.2. Damaged Portable Concrete Barriers/Test Vehicle Geometrics for Test No. 440592-2, Rear View.

6.2. WEATHER CONDITIONS

Table 6.3 shows the weather conditions for Test No. 440592-2.

Table 6.3. Weather Conditions for Test No. 440592-2.

Date of Test	December 8, 2021 AM
Temperature (°F)	67
Relative Humidity (%)	82
Wind Direction (deg)	196
Vehicle Traveling (deg)	350
Wind Speed (mi/h)	1

6.3. TEST VEHICLE

Figure 6.3 and Figure 6.4 show the 2016 RAM 1500 used for the crash test. Table 6.4 shows the vehicle measurements. Table D.1 in Appendix D.1 gives additional dimensions and information on the vehicle.

Figure 6.3. Test Vehicle before Test No. 440592-2, Front View.

Figure 6.4. Test Vehicle before Test No. 440592-2, Front View Close-Up.

Table 6.4. Vehicle Measurements for Test No. 440592-2.

Test Parameter	***MASH***	**Allowed Tolerance**	**Actual Measured**
Dummy (if applicable)[a] (lb)	165	N/A	N/A
Curb Weight (lb)	5000	N/A	4990
Gross Static[a] (lb)	5000	±110	5064
Wheelbase (inches)	148	±12	140.5
Front Overhang (inches)	39	±3	40
Overall Length (inches)	237	±13	227.5
Overall Width (inches)	78	±2	78.5
Hood Height (inches)	43	±4	46
Track Width[b] (inches)	67	±1.5	68.3
CG aft of Front Axle[c] (inches)	63	±4	60.8
CG above Ground[c,d] (inches)	28	≥28	28.3

[a] If a dummy is used, the gross static vehicle mass should be increased by the mass of the dummy.
[b] Average of front and rear axles.
[c] For test inertial mass.
[d] 2270P vehicle must meet minimum CG height requirement.

6.4. TEST DESCRIPTION

Table 6.5 lists events that occurred during Test No. 440592-2. Figures D.2 and D.3 in Appendix D.2 present sequential photographs during the test.

Table 6.5. Events during Test No. 440592-2.

Time (s)	Events
0.0000	Vehicle impacts the installation
0.0410	Vehicle begins to redirect
0.0425	Crack begins to form on field side of barrier 4 near joint 3–4
0.0790	Front passenger side tire lifts off pavement
0.1440	Rear passenger side tire lifts off pavement
0.2340	Vehicle travels parallel with installation
0.5910	Front passenger side tire makes contact with the pavement

6.5. DAMAGE TO TEST INSTALLATION

There was significant spalling at the upstream end of barrier 4 and a small amount near its scupper. The existing cracks before impact ranged in size from 0.1 mm to 0.15 mm, and post impact, they were between 0.1 mm and 3 mm. The existing spall on the field side toe of barrier 4 increased in size from 24 inches wide × 5 inches high × 2 inches deep to 24 inches wide × 32 inches high × 8.6 inches deep. There was no additional spalling on the traffic side at the joint of barriers 3 and 4. The JJ hook on the downstream end of barrier 2 bent 4 degrees, and the JJ hook on the upstream end of barrier 3 bent 5 degrees. The JJ hook on the downstream end of barrier 3 bent 8 degrees, and the JJ hook on the upstream end of barrier 4 bent 10 degrees.

Table 6.6 and Table 6.7 describe the barrier movement and damage, respectively, to the damaged portable concrete barriers. Figure 6.5 shows the damage to the damaged portable concrete barriers.

Table 6.6. Barrier Movement of Damaged Portable Concrete Barrier, Test No. 440592-2.

Joint/Barrier	Movement D/S (inches)	Movement U/S (inches)	Movement T/S (inches)	Movement F/S (inches)	Comments
1	6	—	$1^1/_2$	—	—
1/2	6	—	—	2	—
2/3	$7^1/_2$	—	$3^1/_4$	—	—
3/4	—	—	—	56	—
4/5	—	$1^1/_2$	—	4.5	—
5/6	—	$1^1/_2$	—	2	—
6/7	—	1	—	—	—
7	—	1	—	—	—

Note: D/S = Downstream, U/S = Upstream, T/S = Traffic Side, F/S = Field Side. A dash indicates “none.”

Table 6.7. Damage to Damaged Portable Concrete Barrier, Test No. 440592-2.

Test Parameter	Measured
Permanent Deflection/Location	56 inches toward field side at the joint between barriers 3 and 4
Dynamic Deflection	56 inches toward field side
Working Width[a] and Height	79.9 inches, at a height of 3 inches

[a] Per MASH, "The working width is the maximum dynamic lateral position of any major part of the system or vehicle. These measurements are all relative to the pre-impact traffic face of the test article." In other words, working width is the total barrier width plus the maximum dynamic intrusion of any portion of the barrier or test vehicle past the field side edge of the barrier.

(a)

(b)

Figure 6.5. Damaged Portable Concrete Barriers after Test No. 440592-2.

(c)

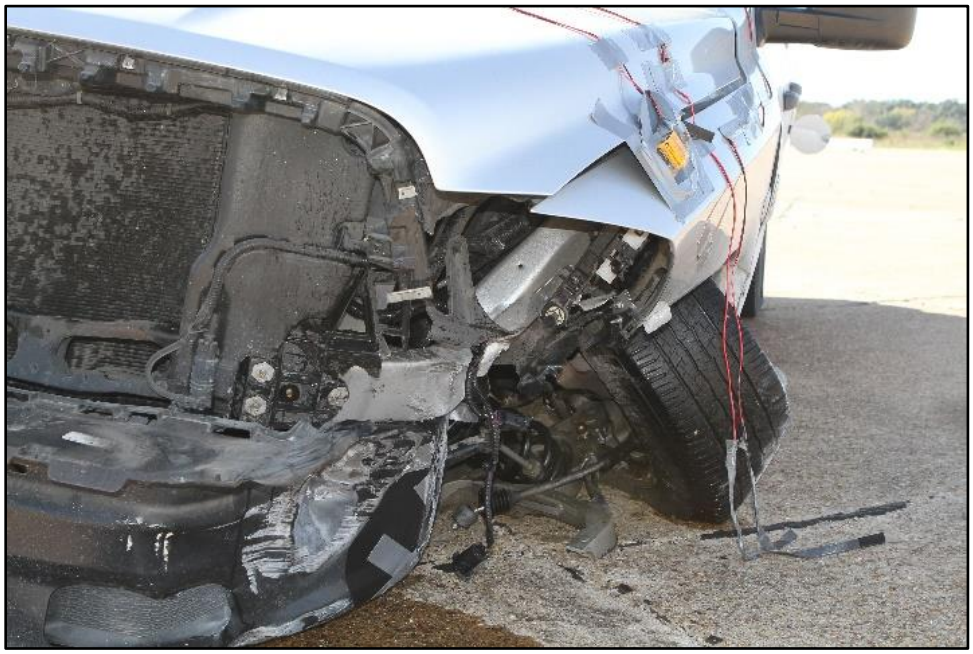
(d)

Figure 6.5. Damaged Portable Concrete Barriers after Test No. 440592-2 (Continued).

6.6. DAMAGE TO TEST VEHICLE

Figures D.2 and D.3 in Appendix D.1 provide exterior crush and occupant compartment measurements. Figure 6.6 shows exterior damage to the test vehicle, and Figure 6.7 shows damage inside the test vehicle. Table 6.8 lists the occupant compartment intrusion measurements, and Table 6.9 lists damage to the vehicle.

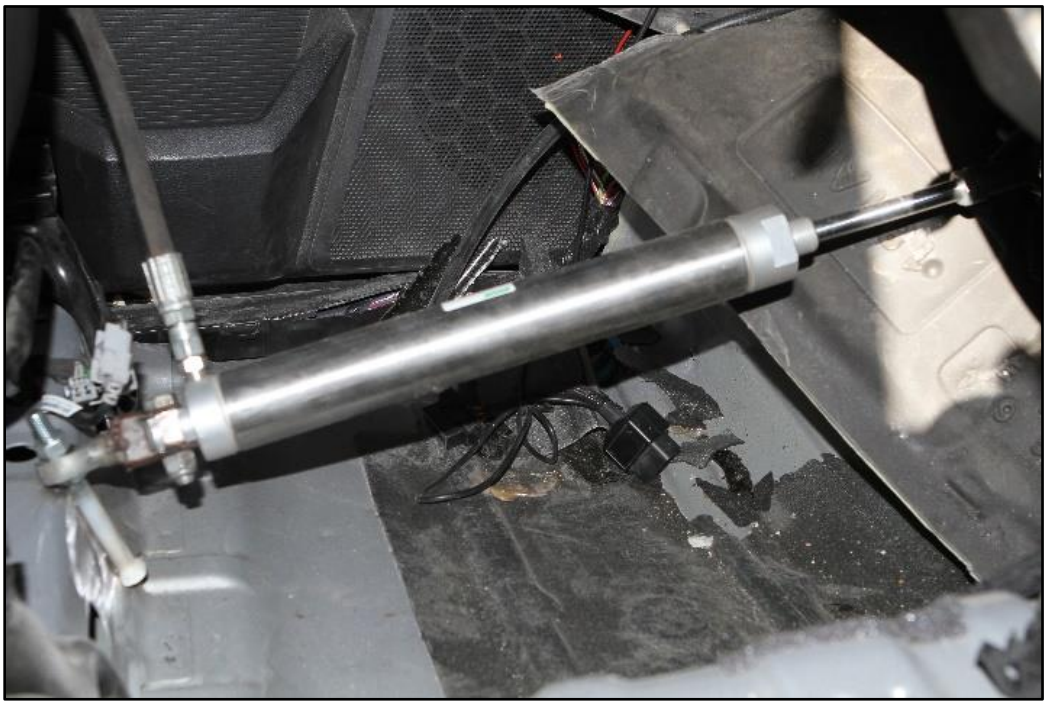
(a)



(b)

Figure 6.6. Test Vehicle after Test No. 440592-2.

(a)



(b)

Figure 6.7. Interior of Test Vehicle after Test No. 440592-2.

Table 6.8. Occupant Compartment Deformation, Test No. 440592-2.

Test Parameter	Specification	Measured
Roof	≤4.0 inches	0 inches
Windshield	≤3.0 inches	0 inches
A and B Pillars	≤5.0 overall/≤3.0 inches lateral	0 inches
Foot Well/Toe Pan	≤9.0 inches	8.5 inches
Floor Pan/Transmission Tunnel	≤12.0 inches	0 inches
Side Front Panel	≤12.0 inches	1 inch
Front Door (above Seat)	≤9.0 inches	0 inches
Front Door (below Seat)	≤12.0 inches	1 inch

Table 6.9. Damage to Vehicle, Test No. 440592-2.

Side Windows	Side windows remained intact
Maximum Exterior Deformation	14 inches in the left plane at the front corner at bumper height
VDS	11LFQ5
CDC	11FLEW3
Fuel Tank Damage	None
Description of Damage to Vehicle:	The front bumper, hood, grill, left headlight, left front tire and rim, left front upper and lower control arms, left tire rod, left front quarter fender, left front door, left front toe panel, left rear door, left rear cab corner, left rear quarter fender, left rear taillight, and rear bumper were damaged.

6.7. OCCUPANT RISK FACTORS

Data from the accelerometers were digitized for evaluation of occupant risk, and the results are shown in Table 6.10. Figure D.6 in Appendix D.3 shows the vehicle angular displacements, and Figures D.7 through D.9 in Appendix D.4 show acceleration versus time traces.

Table 6.10. Occupant Risk Factors for Test No. 440592-2.

Test Parameter	*MASH*	Measured	Time
OIV, Longitudinal (ft/s)	≤40.0	19.6	0.0969 s on left side of interior
OIV, Lateral (ft/s)	≤40.0	23.1	0.0969 s on left side of interior
Ridedown, Longitudinal (g)	≤20.49	5.1	0.0969–0.1069 s
Ridedown, Lateral (g)	≤20.49	9.9	0.2710–0.2810 s
THIV (m/s)	N/A	9.1	0.0946 s on left side of interior
ASI	N/A	1.6	0.0543–0.1043 s
50-ms MA Longitudinal (g)	N/A	−9.2	0.0407–0.0907 s
50-ms MA Lateral (g)	N/A	12.3	0.0356–0.0856 s
50-ms MA Vertical (g)	N/A	−3.3	0.0136–0.0636 s
Roll (deg)	≤75	14	0.4738 s
Pitch (deg)	≤75	11	0.6330 s
Yaw (deg)	N/A	40	1.0316 s

6.8. TEST SUMMARY

Table 6.11, Table 6.12, Figure 6.8, Figure 6.9, and Figure 6.10 summarize the results for Test No. 440592-2.

Table 6.11. Summary of Results for Test No. 440592-2, General Information, Impact and Exit Conditions.

General Information	Test Agency	Texas A&M Transportation Institute
	Test Standard Test No.	*MASH* Test 3-11
	TTI Test No.	440592-2
	Test Date	2021-12-08
Test Article	Type	Portable Concrete Barrier
	Name	Damaged Portable Concrete Barrier
	Installation Length	210 ft 6 inches
	Material or Key Elements	Seven F-Shaped Concrete Barriers
	Foundation Type/Condition	Concrete Apron, Dry
Test Vehicle	Type/Designation	2270P
	Make and Model	2016, RAM 1500
	Curb	4990 lb
	Test Inertial	5064 lb
	Dummy	N/A
	Gross Static	5064 lb
Impact Conditions	Speed	60.4 mi/h
	Angle	24.9 degrees
	Location	4.3 ft upstream from the centerline of the joint between barrier 3 and 4
	Impact Severity	109.5 kip-ft
Exit Conditions	Speed	Out of view (Not measurable)
	Exit Trajectory/Heading	Out of view (Not measurable)

Table 6.12. Summary of Results for Test No. 440592-2, Occupant Risk, Vehicle and Test Article Damage.

Occupant Risk Values	Longitudinal OIV	19.6 ft/s
	Lateral OIV	23.1 ft/s
	Longitudinal RDA	5.1 g
	Lateral RDA	9.9 g
	THIV	9.1 m/s
	ASI	1.6
Max. 0.050-s Average	Longitudinal	−9.2 g
	Lateral	12.3 g
	Vertical	−3.3 g
Post-Impact Trajectory	Stopping Distance	440 ft downstream, 95 ft on traffic side
Vehicle Stability	Maximum Roll Angle	14°
	Maximum Pitch Angle	11°
	Maximum Yaw Angle	40°
	Vehicle Snagging	No indication of snagging
	Vehicle Pocketing	No indication of pocketing
Test Article Deflections	Dynamic	56 inches
	Permanent	56 inches
	Working Width	79.9 inches
	Height of Working Width	3 inches
Vehicle Damage	VDS	11LFQ5
	CDC	11FLEW3
	Max. Exterior Deformation	14 inches at left front bumper
	Max. Occupant Compartment Deformation	8½ inches, left toe pan area

(a) 0.000 s

(b) 0.100 s

Figure 6.8. Summary of Results for Test No. 440592-2, Sequential Test Pictures.

(c) 0.200 s

(d) 0.300 s

Figure 6.8. Summary of Results for Test No. 440592-2, Sequential Test Pictures (Continued).

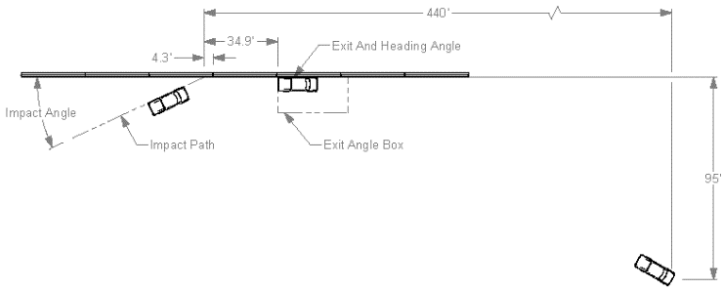


Figure 6.9. Summary of Results for Test No. 440592-2, Summary Drawing.

0.000 s

0.100 s

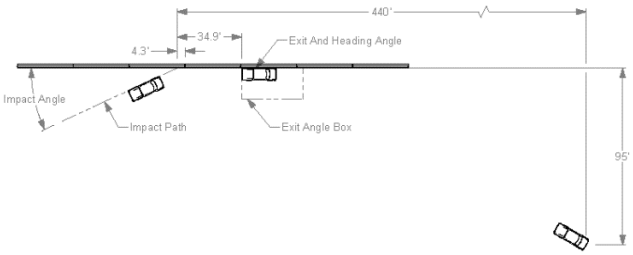
0.200 s

0.300 s

Test Agency	Texas A&M Transportation Institute (TTI)
Test Standard/Test No.	*MASH* 2016, Test 3-11
TTI Project No.	440592-2
Test Date	2021-12-08
TEST ARTICLE	
Type	Portable Concrete Barrier
Name	Damaged Portable Concrete Barrier
Length	210 ft 6 inches
Key Materials	7 F-Shaped Concrete Barriers
Soil Type and Condition	Concrete Apron, Dry
TEST VEHICLE	
Type/Designation	2270P
Year, Make and Model	2016 RAM 1500
Curb Weight (lb)	4990
Inertial Weight (lb)	5064
Dummy (lb)	N/A
Gross Static (lb)	5064
IMPACT CONDITIONS	
Impact Speed (mi/h)	60.4
Impact Angle (deg)	24.9
Impact Location	4.3 ft upstream of the center of the joint between barriers 3 and 4
Impact Severity (kip-ft)	109.5
EXIT CONDITIONS	
Exit Speed (mi/h)	Out of view (not measurable)
Trajectory/Heading Angle (deg)	Out of view (not measurable)
Exit Box Criteria	Vehicle crossed exit angle box
Stopping Distance	440 ft downstream of impact point 95 ft to the traffic side of the installation
TEST ARTICLE DEFLECTIONS	
Dynamic (inches)	56
Permanent (inches)	56
Working Width/Height (inches)	79.9/3
VEHICLE DAMAGE	
VDS	11LFQ5
CDC	11FLEW3
Max. Ext. Deformation (inches)	14, at Left Front Bumper
Max Occupant Compartment Deformation (inches)	8½, Left Toe Pan Area

OCCUPANT RISK VALUES

Long. OIV (ft/s)	19.6	Long. Ridedown (g)	5.1	Max 50-ms Long. (g)	−9.2	Max Roll (deg)	14
Lat. OIV (ft/s)	23.1	Lat. Ridedown (g)	9.9	Max 50-ms Lat. (g)	12.3	Max Pitch (deg)	11
THIV (m/s)	9.1	ASI	1.6	Max 50-ms Vert. (g)	−3.3	Max Yaw (deg)	40



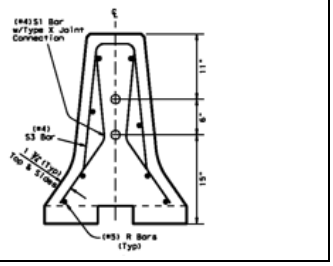


Figure 6.10. Summary of Results for *MASH* Test 3-11 on Damaged Portable Concrete Barriers, Test No. 440592-2.

Chapter 7. SUMMARY AND CONCLUSIONS

7.1. ASSESSMENT OF TEST RESULTS

The crash tests reported herein were performed in accordance with *MASH* Test 3-11, which involved two tests, on the damaged portable concrete barriers. Table 7.1 and Table 7.2 provide an assessment of each test based on the applicable safety evaluation criteria for *MASH* TL-3 longitudinal barriers.

7.2. CONCLUSIONS

Table 7.3 shows that the damaged portable concrete barriers met the performance criteria for *MASH* Test 3-11.

Table 7.1. Performance Evaluation Summary for *MASH* Test 3-11 on Damaged Portable Concrete Barrier, Test No. 440592-1.

Evaluation Factors	**Evaluation Criteria**		***Assessment***
Structural Adequacy	A.	The damaged portable concrete barrier contained and redirected the 2270P vehicle. The vehicle did not penetrate, underride, or override the installation. Maximum dynamic deflection during the test was 60.9 inches.	Pass
Occupant Risk	D.	No detached elements, fragments, or other debris from the transition was present to penetrate or show potential for penetrating the occupant compartment, or present hazard to others in the area. Maximum occupant compartment deformation was 1.0 inch in the left kick panel area.	Pass
	F.	The 2270P vehicle remained upright during and after the collision event. Maximum roll and pitch angles were 17 degrees and 16 degrees.	Pass
	H.	Longitudinal OIV was 12.3 ft/s, and lateral OIV was 21.5 ft/s.	Pass
	I.	Longitudinal occupant RA was 5.0 g, and lateral occupant RA was 12.6 g.	Pass

Table 7.2. Performance Evaluation Summary for *MASH* Test 3-11 on Damaged Portable Concrete Barrier, Test No. 440592-2.

Evaluation Factors	**Evaluation Criteria**		***Assessment***
Structural Adequacy	A.	The damaged portable concrete barrier contained and redirected the 2270P vehicle. The vehicle did not penetrate, underride, or override the installation. Maximum dynamic deflection during the test was 56 inches.	Pass
Occupant Risk	D.	No detached elements, fragments, or other debris from the transition was present to penetrate or show potential for penetrating the occupant compartment, or present hazard to others in the area. Maximum occupant compartment deformation was 8.5 inches in the left front toe pan area.	Pass
	F.	The 2270P vehicle remained upright during and after the collision event. Maximum roll and pitch angles were 14 degrees and 11 degrees.	Pass
	H.	Longitudinal OIV was 19.6 ft/s, and lateral OIV was 23.1 ft/s.	Pass
	I.	Longitudinal occupant RA was 5.1 g, and lateral occupant RA was 9.9 g.	Pass

Table 7.3. Assessment Summary for *MASH* TL-3 Tests on Damaged Portable Concrete Barriers.

Evaluation Factors	Evaluation Criteria	Test No. 440592-1	Test No. 440592-2
Structural Adequacy	A	S	S
Occupant Risk	D	S	S
	F	S	S
	H	S	S
	I	S	S
Result	Pass/Fail	Pass	Pass

Note: S = Satisfactory.

REFERENCES

1. AASHTO. *Manual for Assessing Roadside Safety Hardware*, Second Edition. American Association of State Highway and Transportation Officials, Washington, DC, 2016.

APPENDIX A. DETAILS ON DAMAGED PORTABLE CONCRETE BARRIERS

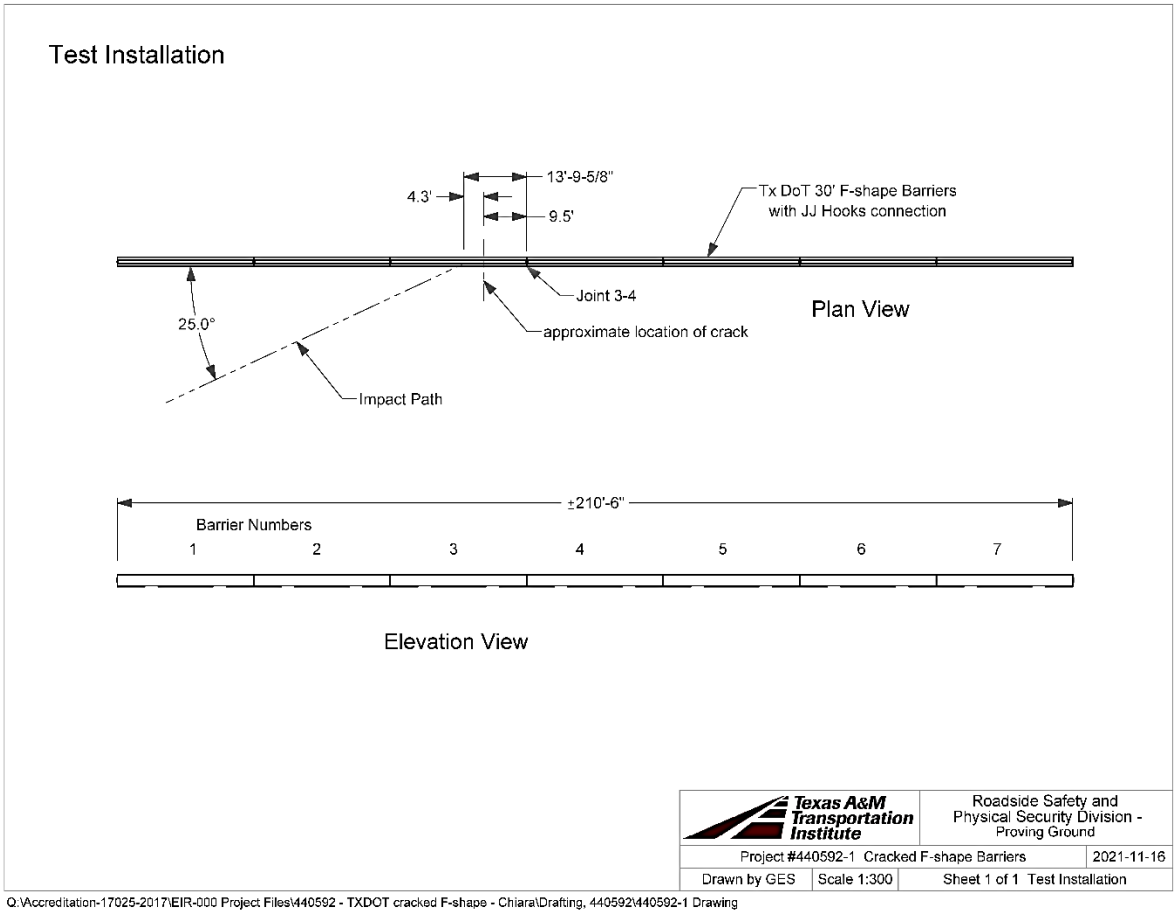


Figure A.1. Layout Drawing for Test No. 440592-1.

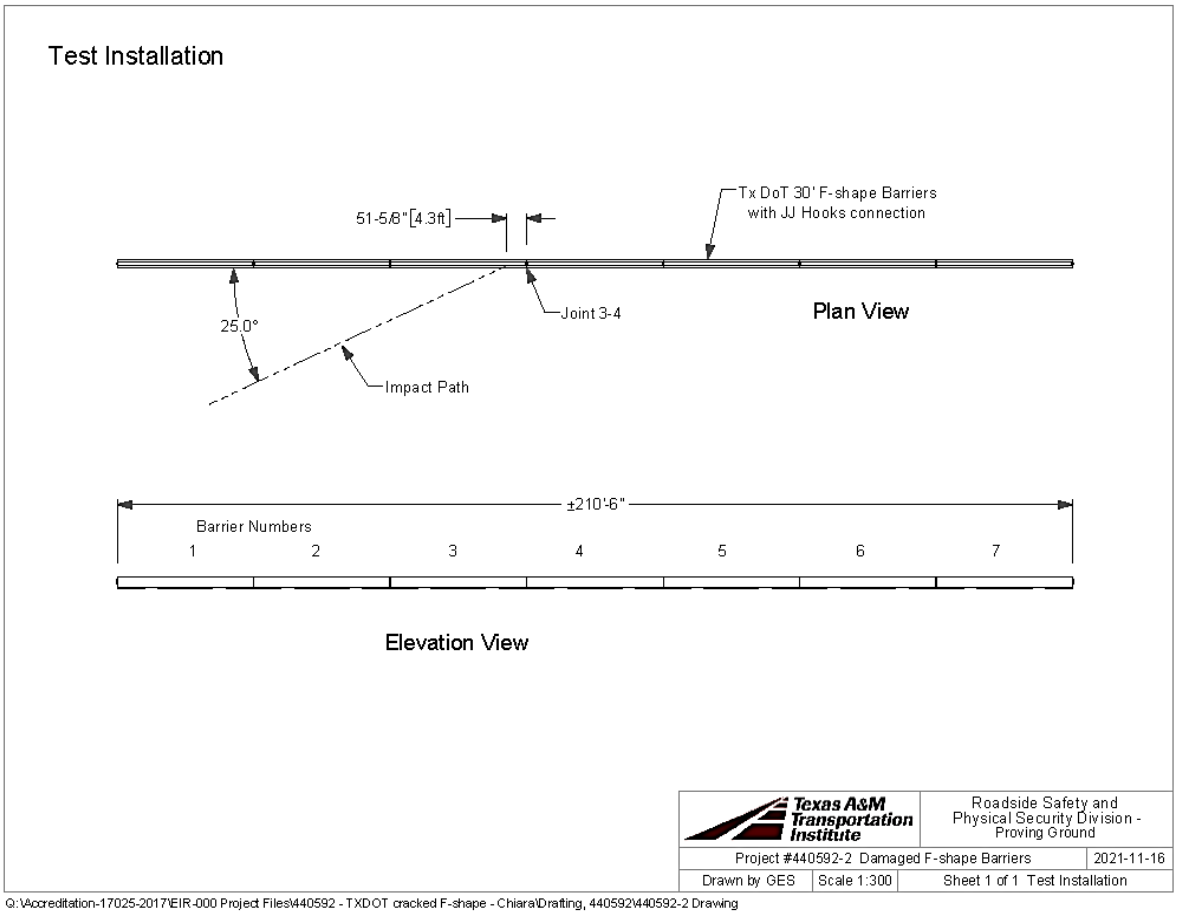


Figure A.2. Layout Drawing for Test No. 440592-2.

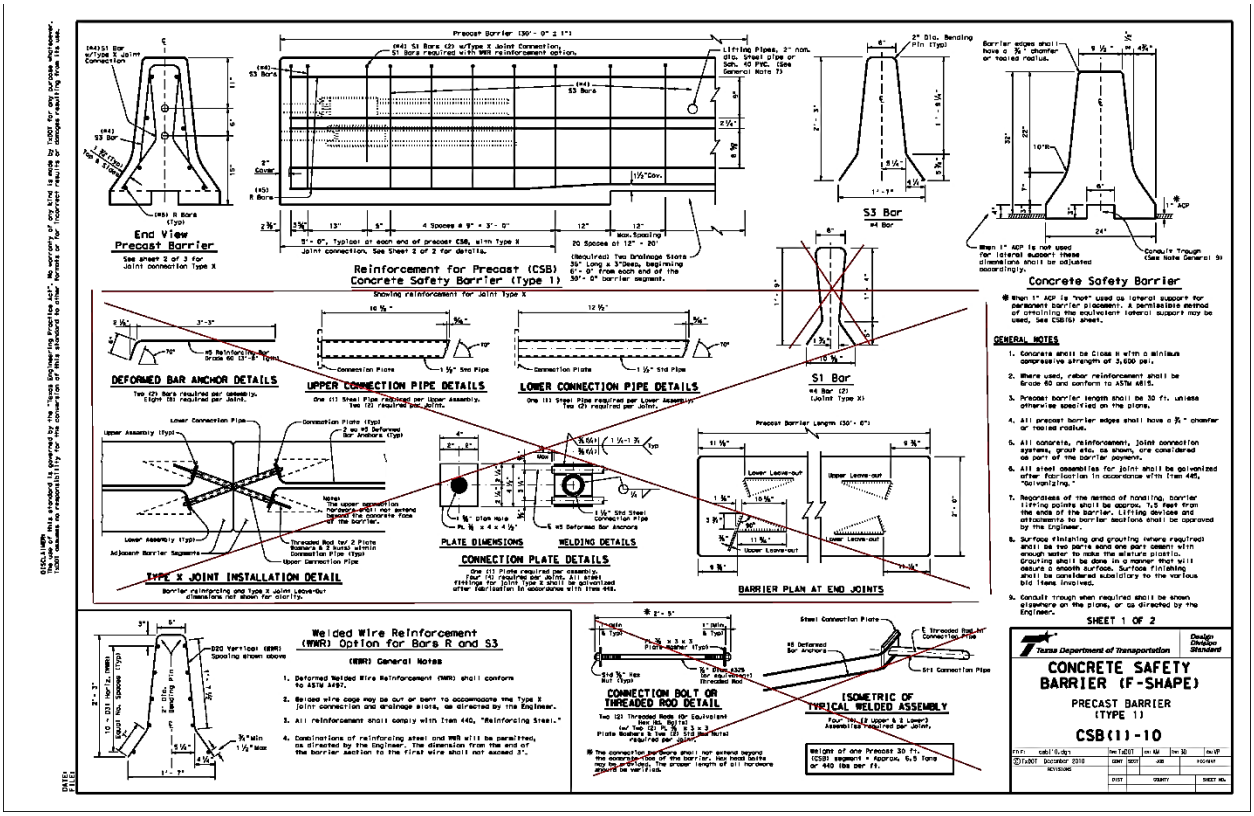


Figure A.3. Detailed Drawing for Barriers Used during Testing.

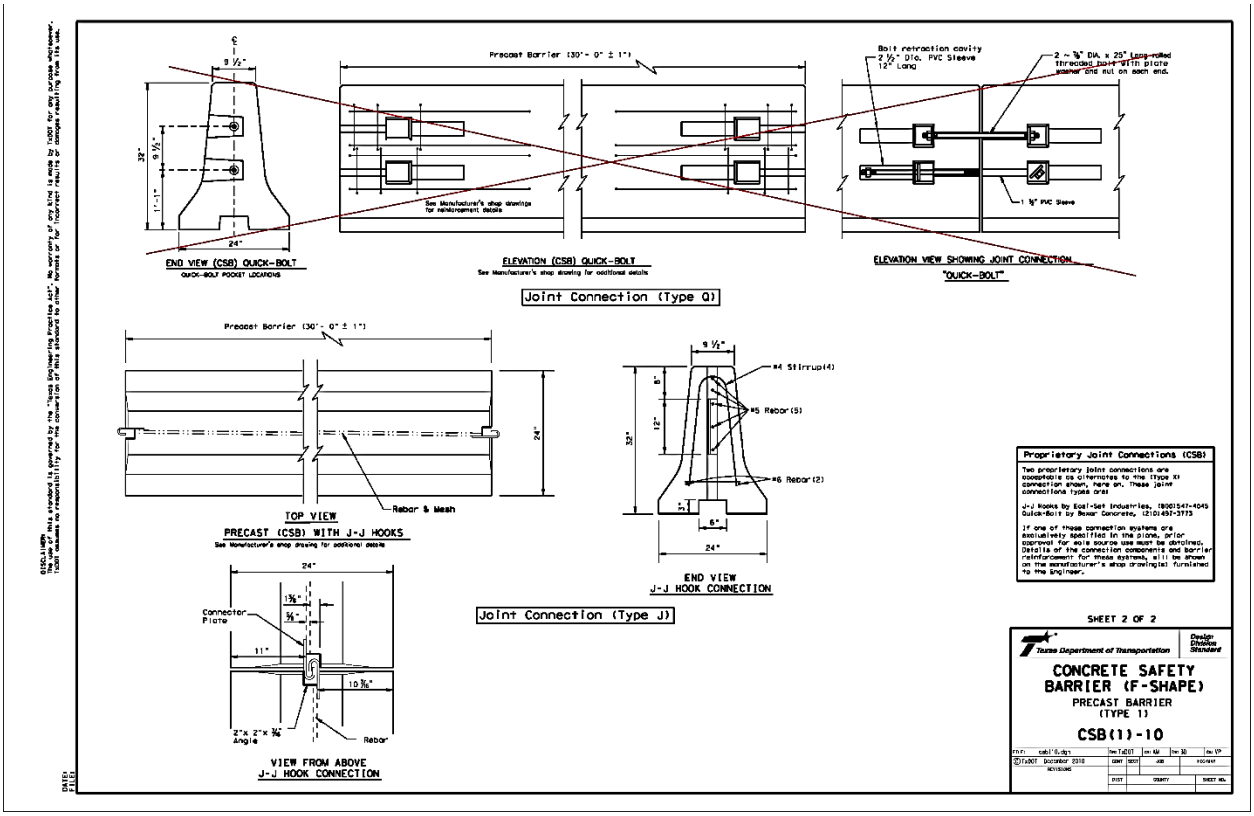


Figure A.4. Detailed Drawing of Connections for Barriers Used during Testing.

APPENDIX B. SUPPORTING CERTIFICATION DOCUMENTS

Concrete Core Test Report

Report Numb A1171057.0219
Service Dat 12/16/21
Report Date 01/03/22
Task: PO# 440592

Terracon
6198 Imperial Loop
College Station, TX 77845-5765
979-846-3767 Reg No: F-3272

Client

Texas Transportation Institute
Attn: Gary Gerke
TTI Business Office
3135 TAMU
College Station, TX 77843-3135

Project

Riverside Campus
Riverside Campus
Bryan, TX

Project Number: A1171057

Material Information

Specified Str
Specified Len
Mix ID:
Nominal Maximum Size Ag

Sample Information

Placement D
Date Tested 12/15/21 **Time:** 0000
Sampled By:
Drill Direc Vertical
Date Core Obta 12/15/21 **Time:** 0000
Date Ends Trim 12/15/21 **Time:** 0000
Moisture Conditioning According to ASTM C-42

Laboratory Test Data

Core ID	Location	Cored Length (in)	Trim Length (in)	Capped Length (in)	Diam. (in)	Area (sq in	Length / Diam. Ra	Max Loa (lbs)	Corr. Facto	Comp. Strength (psi)	Fractu Type	Densit (pcf)	Tested By
1	Barrier	9.12	4.58	4.58	4.00	12.57	1.15	100780	0.906	7270	3		JEW
2	Barrier	9.36	4.92	4.92	4.00	12.57	1.23	111520	0.925	8210	3		JEW
3	Barrier	9.59	5.91	5.91	4.00	12.57	1.48	75240	0.958	5740	3		JEW

Comments

Services:
Terracon Rep.: Cullen Turney
Reported To
Contractor:
Report Distribution:
(1) Texas Transportation Institute, Gary Gerke
(1) Texas Transportation Institute, Bill Griffith

Start/Stop: 0800-1300

Reviewed By: Alexander Dunigan
Project Manager

Test Met

The tests were performed in general accordance with applicable ASTM, AASHTO, or DOT test methods. This report is exclusively for the use of the client indicated above and shall not be reproduced except in full without the written consent of our company. Test results transmitted herein are only applicable to

CR0004.11-1

Page 1 of 1

Figure B.1. Concrete Report.

APPENDIX C. *MASH* TEST 3-11 (CRASH TEST NO. 440592-1)

C.1. VEHICLE PROPERTIES AND INFORMATION

Date: 2021-12-1 Test No.: 440592-1 VIN No.: 1C6RR6GS164205

Year: 2016 Make: RAM Model:

Tire Size: 265/70 R 17 Tire Inflation Pressure: 35 psi

Tread Type: Highway Odometer: 158475

Note any damage to the vehicle prior to test: None

● Denotes accelerometer location.

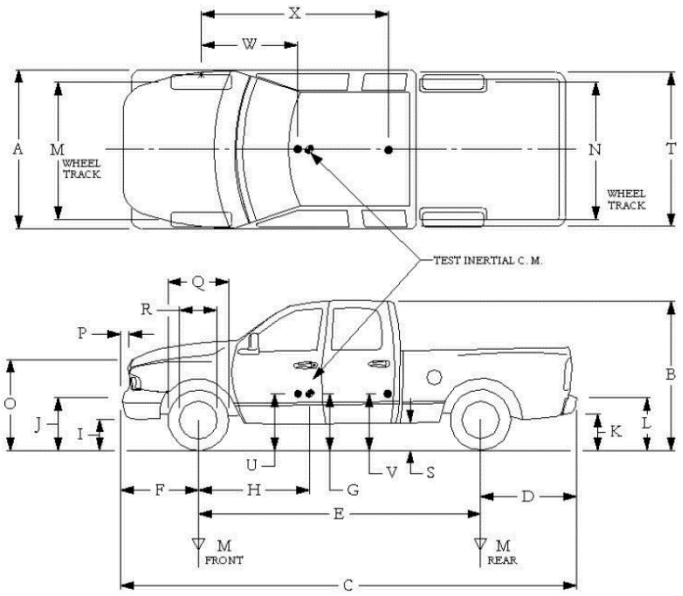
NOTES: None

Engine Type: V-8
Engine CID: 5.7 L

Transmission Type:
☑ Auto or ☐ Manual
☐ FWD ☑ RWD ☐ 4WD

Optional Equipment:
None

Dummy Data:
Type: NONE
Mass: 0 lb
Seat Position:



Geometry: inches

A	78.50	F	40.00	K	20.00	P	3.00	U	26.75
B	74.00	G	28.6	L	30.00	Q	30.50	V	30.25
C	227.50	H	59.58	M	68.50	R	18.00	W	59.5
D	44.00	I	11.75	N	68.00	S	13.00	X	79
E	140.50	J	27.00	O	46.00	T	77.00		

Wheel Center Height Front	14.75	Wheel Well Clearance (Front)	6.00	Bottom Frame Height - Front	12.50
Wheel Center Height Rear	14.75	Wheel Well Clearance (Rear)	9.25	Bottom Frame Height - Rear	22.50

RANGE LIMIT: A=78 ±2 inches; C=237 ±13 inches; E=148 ±12 inches; F=39 ±3 inches; G = > 28 inches; H = 63 ±4 inches; O=43 ±4 inches; (M+N)/2=67 ±1.5 inches

GVWR Ratings:		**Mass:** lb	Curb	Test Inertial	Gross Static
Front	3700	M_{front}	2958	2894	2894
Back	3900	M_{rear}	2125	2131	2131
Total	6700	M_{Total}	5083	5025	5025

(Allowable Range for TIM and GSM = 5000 lb ±110 lb)

Mass Distribution:
lb LF: 1456 RF: 1438 LR: 1122 RR: 1009

Figure C.1. Vehicle Properties for Test No. 440592-1.

Date:	2021-12-01	Test No.:	440592-1	VIN No.:	1C6RR6GS164205
Year:	2016	Make:	RAM	Model:	1500

VEHICLE CRUSH MEASUREMENT SHEET[1]

Complete When Applicable	
End Damage	Side Damage
Undeformed end width _____	Bowing: B1 _____ X1 _____
Corner shift: A1 _____	B2 _____ X2 _____
A2 _____	
End shift at frame (CDC)	Bowing constant
(check one)	$\frac{X1+X2}{2}$ = _____
< 4 inches _____	
≥ 4 inches _____	

Note: Measure C_1 to C_6 from Driver to Passenger Side in Front or Rear Impacts – Rear to Front in Side Impacts.

Specific Impact Number	Plane* of C-Measurements	Direct Damage		Field L**	C_1	C_2	C_3	C_4	C_5	C_6	±D
		Width** (CDC)	Max*** Crush								
1	AT FT BUMPER	18	12	36							18
2	SAME	18	12	60							76
	Measurements recorded										
	☑ **inches or** ☐ **mm**										

[1]Table taken from National Accident Sampling System (NASS).

*Identify the plane at which the C-measurements are taken (e.g., at bumper, above bumper, at sill, above sill, at beltline, etc.) or label adjustments (e.g., free space).

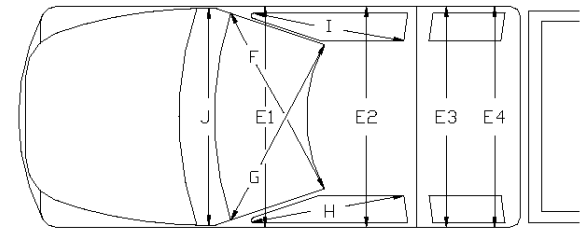
Free space value is defined as the distance between the baseline and the original body contour taken at the individual C locations. This may include the following: bumper lead, bumper taper, side protrusion, side taper, etc. Record the value for each C-measurement and maximum crush.

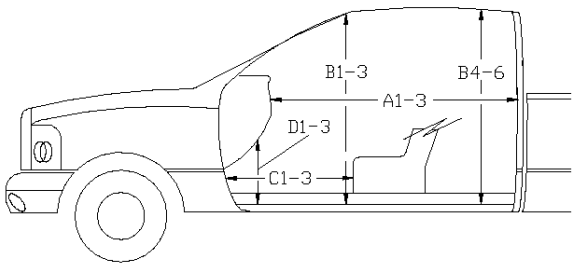
**Measure and document on the vehicle diagram the beginning or end of the direct damage width and field L (e.g., side damage with respect to undamaged axle).

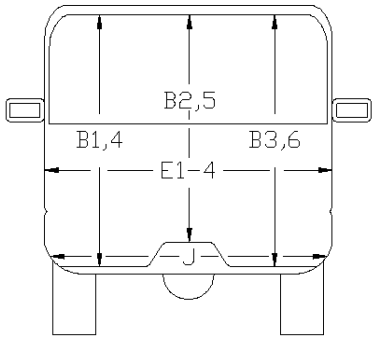
***Measure and document on the vehicle diagram the location of the maximum crush.

Figure C.2. Exterior Crush Measurements for Test No. 440592-1.

Date:	2021-12-01	Test No.:	440592-1	VIN No.:	1C6RR6GS164205
Year:	2016	Make:	RAM	Model:	1500







*Lateral area across the cab from driver's side kickpanel to passenger's side kickpanel.

OCCUPANT COMPARTMENT DEFORMATION MEASUREMENT

	Before	After (inches)	Differ.
A1	65.00	65.00	0.00
A2	63.00	63	0.00
A3	65.50	65.50	0.00
B1	45.00	45.00	0.00
B2	38.00	38.00	0.00
B3	45.00	45.00	0.00
B4	39.50	39.50	0.00
B5	43.00	43.00	0.00
B6	39.50	39.50	0.00
C1	26.00	26.00	0.00
C2	0.00	0.00	0.00
C3	26.00	26.00	0.00
D1	11.00	11.00	0.00
D2	0.00	0.00	0.00
D3	11.50	11.50	0.00
E1	58.50	57.5	1
E2	63.50	64.5	1
E3	63.50	63.50	0.00
E4	63.50	63.50	0.00
F	59.00	59.00	0.00
G	59.00	59.00	0.00
H	37.50	37.50	0.00
I	37.50	37.50	0.00
J*	25.00	25.00	0.00

Figure C.3. Occupant Compartment Measurements for Test No. 440592-1.

C.2. SEQUENTIAL PHOTOGRAPHS

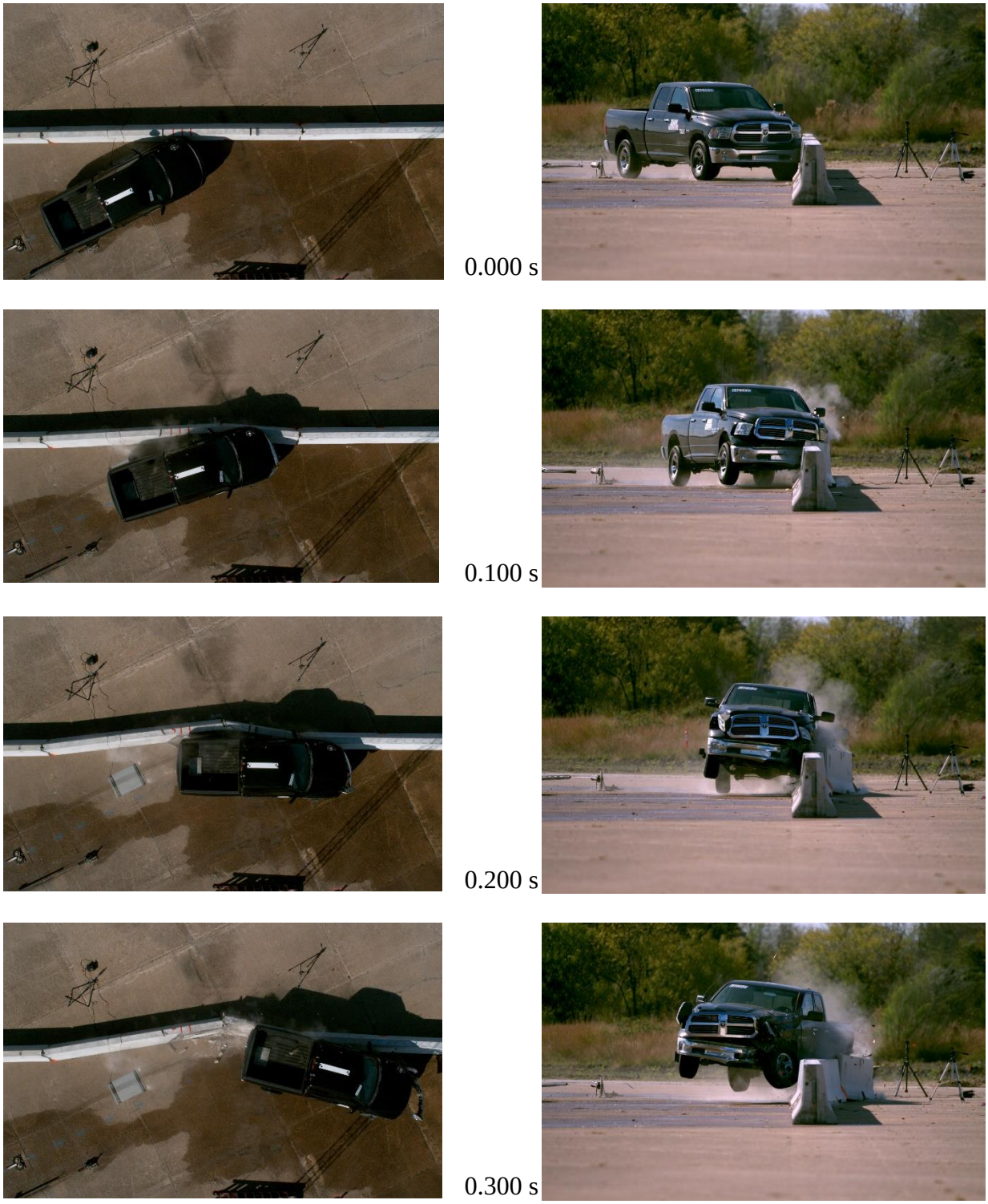


Figure C.4. Sequential Photographs for Test No. 440592-1 (Overhead and Frontal Views).


0.400 s



0.500 s



0.600 s



0.700 s


Figure C.4. Sequential Photographs for Test No. 440592-1 (Overhead and Frontal Views) (Continued).

0.000 s

0.400 s

0.100 s

0.500 s

0.200 s

0.600 s

0.300 s

0.700 s

Figure C.5. Sequential Photographs for Test No. 440592-1 (Rear View).

C.3. VEHICLE ANGULAR DISPLACEMENTS

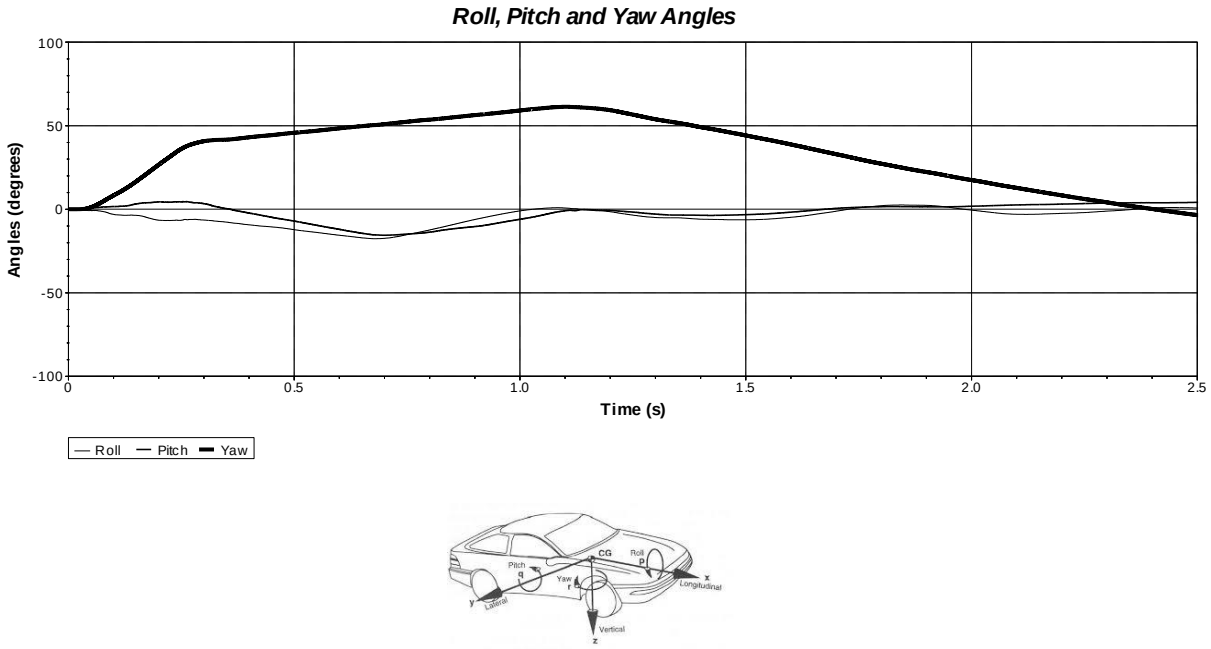


Figure C.6. Vehicle Angular Displacements for Test No. 440592-1.

C.4. VEHICLE ACCELERATIONS

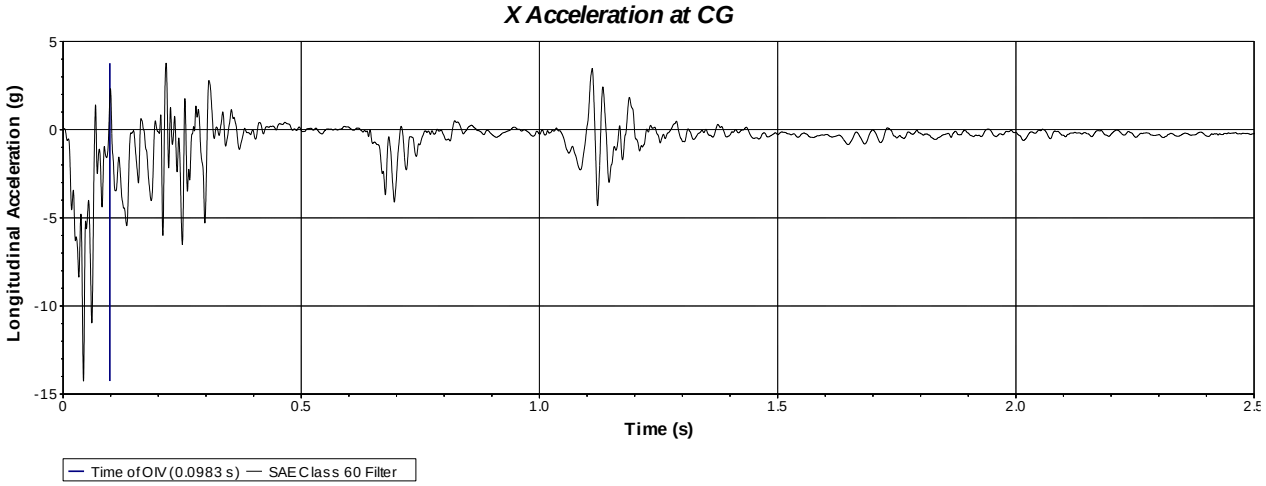


Figure C.7. Vehicle Longitudinal Accelerometer Trace for Test No. 440592-1 (Accelerometer Located at Center of Gravity).

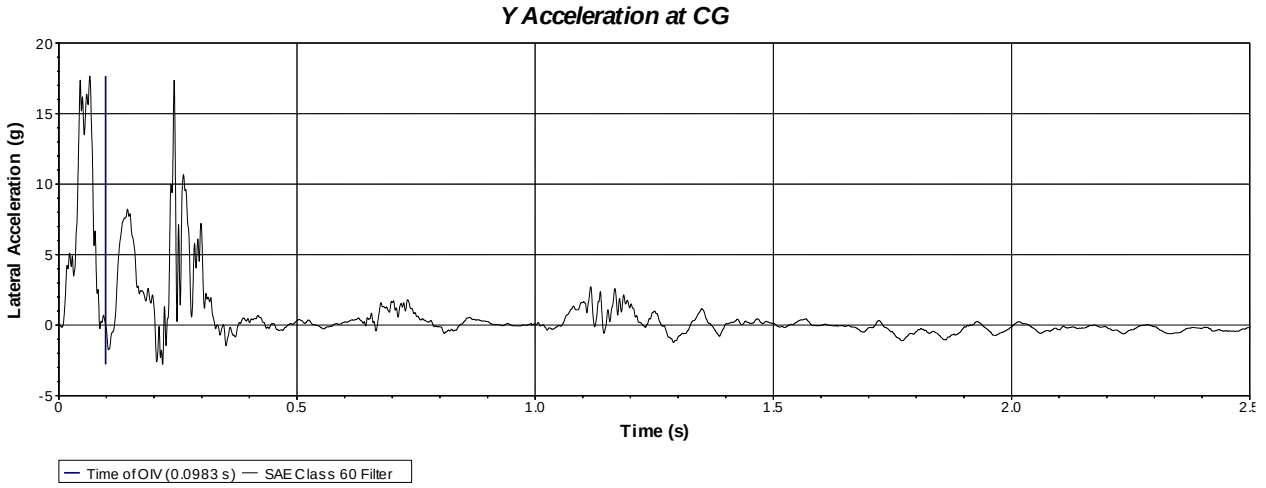


Figure C.8. Vehicle Lateral Accelerometer Trace for Test No. 440592-1 (Accelerometer Located at Center of Gravity).

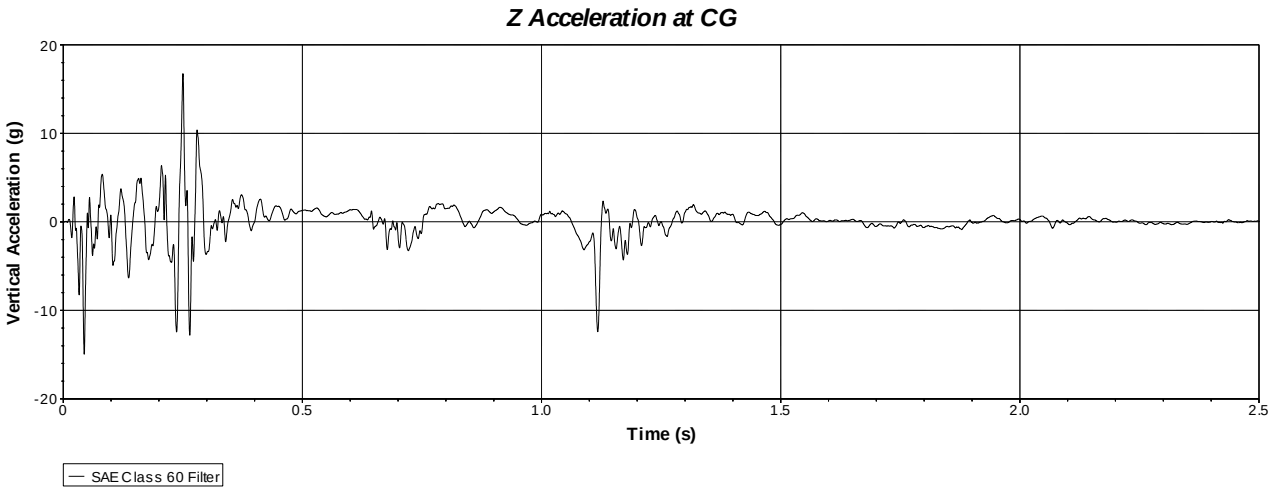


Figure C.9. Vehicle Vertical Accelerometer Trace for Test No. 440592-1 (Accelerometer Located at Center of Gravity).

APPENDIX D. *MASH* TEST 3-11 (CRASH TEST NO. 440592-2)

D.1 VEHICLE PROPERTIES AND INFORMATION

Date: 2021-12-8 Test No.: 440592-2 VIN No.: 1C6RR6FT3GS10751

Year: 2016 Make: RAM Model:

Tire Size: 265/70 R 17 Tire Inflation Pressure: 35 psi

Tread Type: Highway Odometer: 111318

Note any damage to the vehicle prior to test: None

• Denotes accelerometer location.

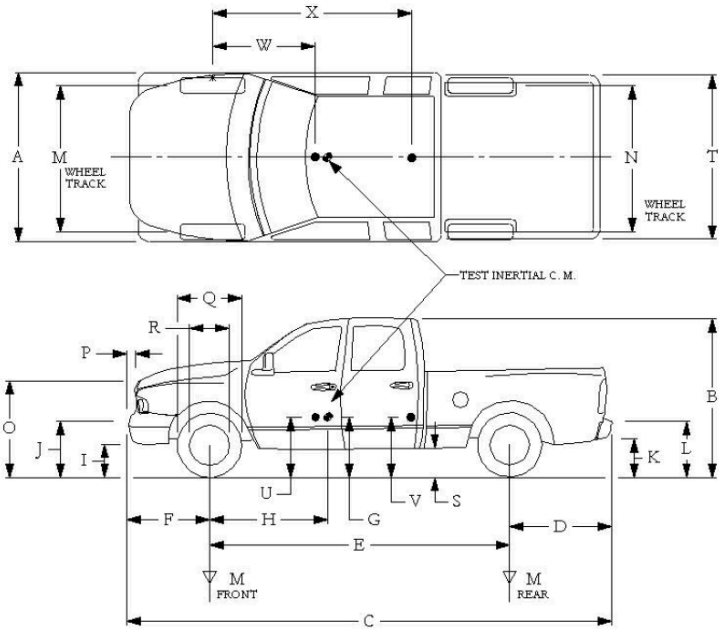
NOTES: None

Engine Type: V-8
Engine CID: 5.7 L

Transmission Type:
☑ Auto or ☐ Manual
☐ FWD ☑ RWD ☐ 4WD

Optional Equipment:
None

Dummy Data:
Type: NONE
Mass: 0 lb
Seat Position:



Geometry: inches

A	78.50	F	40.00	K	20.00	P	3.00	U	26.75
B	74.00	G	28.25	L	30.00	Q	30.50	V	30.25
C	227.50	H	60.84	M	68.50	R	18.00	W	60.8
D	44.00	I	11.75	N	68.00	S	13.00	X	79
E	140.50	J	27.00	O	46.00	T	77.00		

Wheel Center Height Front	14.75	Wheel Well Clearance (Front)	6.00	Bottom Frame Height - Front	12.50
Wheel Center Height Rear	14.75	Wheel Well Clearance (Rear)	9.25	Bottom Frame Height - Rear	22.50

RANGE LIMIT: A=78 ±2 inches; C=237 ±13 inches; E=148 ±12 inches; F=39 ±3 inches; G = > 28 inches; H = 63 ±4 inches; O=43 ±4 inches; (M+N)/2=67 ±1.5 inches

GVWR Ratings:		**Mass:** lb	Curb	Test Inertial	Gross Static
Front	3700	M_{front}	2923	2871	2871
Back	3900	M_{rear}	2067	2193	2193
Total	6700	M_{Total}	4990	5064	5064

(Allowable Range for TIM and GSM = 5000 lb ±110 lb)

Mass Distribution:
lb LF: 1470 RF: 1401 LR: 1074 RR: 1119

Figure D.1. Vehicle Properties for Test No. 440592-2.

Date:	2021-12-08	Test No.:	440592-2	VIN No.:	1C6RR6FT3GS10751
Year:	2016	Make:	RAM	Model:	1500

VEHICLE CRUSH MEASUREMENT SHEET[1]

Complete When Applicable	
End Damage	Side Damage
Undeformed end width _____	Bowing: B1 _____ X1 _____
Corner shift: A1 _____	B2 _____ X2 _____
A2 _____	
End shift at frame (CDC)	Bowing constant
(check one)	$\frac{X1+X2}{2}$ = _____
< 4 inches _____	
≥ 4 inches _____	

Note: Measure C_1 to C_6 from Driver to Passenger Side in Front or Rear Impacts – Rear to Front in Side Impacts.

Specific Impact Number	Plane* of C-Measurements	Direct Damage		Field L***	C_1	C_2	C_3	C_4	C_5	C_6	±D
		Width** (CDC)	Max**** Crush								
1	AT FT BUMPER	15	12	36							18
2	SAME	15	14	60							72
	Measurements recorded										
	☑ **inches or** ☐ **mm**										

[1]Table taken from National Accident Sampling System (NASS).

*Identify the plane at which the C-measurements are taken (e.g., at bumper, above bumper, at sill, above sill, at beltline, etc.) or label adjustments (e.g., free space).

Free space value is defined as the distance between the baseline and the original body contour taken at the individual C locations. This may include the following: bumper lead, bumper taper, side protrusion, side taper, etc. Record the value for each C-measurement and maximum crush.

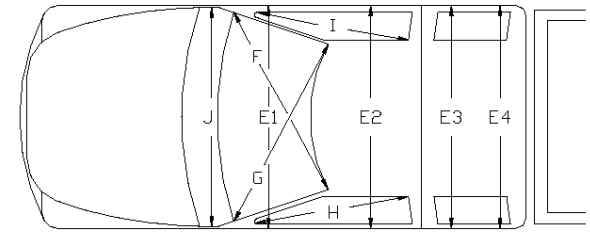
**Measure and document on the vehicle diagram the beginning or end of the direct damage width and field L (e.g., side damage with respect to undamaged axle).

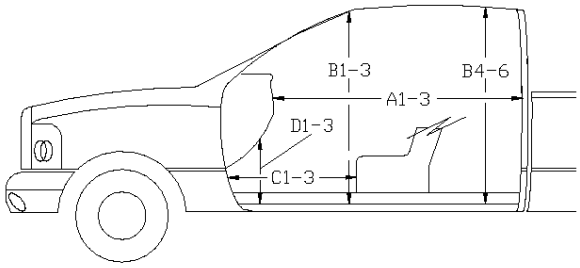
***Measure and document on the vehicle diagram the location of the maximum crush.

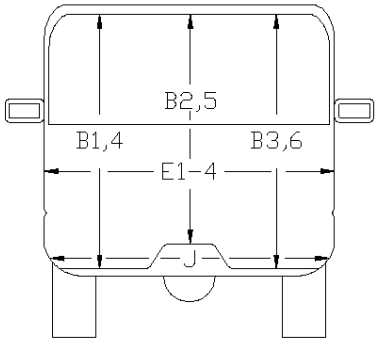
Note: Use as many lines/columns as necessary to describe each damage profile.

Figure D.2. Exterior Crush Measurements for Test No. 440592-2.

Date:	2021-12-08	Test No.:	440592-2	VIN No.:	1C6RR6FT3GS10751
Year:	2016	Make:	RAM	Model:	1500







*Lateral area across the cab from driver's side kickpanel to passenger's side kickpanel.

OCCUPANT COMPARTMENT DEFORMATION MEASUREMENT

	Before	After (inches)	Differ.
A1	65.00	65.00	0.00
A2	63.00	63	0.00
A3	65.50	65.50	0.00
B1	45.00	45.00	0.00
B2	38.00	38.00	0.00
B3	45.00	45.00	0.00
B4	39.50	39.50	0.00
B5	43.00	43.00	0.00
B6	39.50	39.50	0.00
C1	26.00	17.5	8.5
C2	0.00	0.00	0.00
C3	26.00	26.00	0.00
D1	11.00	11.00	0.00
D2	0.00	0.00	0.00
D3	11.50	11.50	0.00
E1	58.50	59.5	1
E2	63.50	64.5	1
E3	63.50	63.50	0.00
E4	63.50	63.50	0.00
F	59.00	59.00	0.00
G	59.00	59.00	0.00
H	37.50	37.50	0.00
I	37.50	37.50	0.00
J*	25.00	21.5	3.5

Figure D.3. Occupant Compartment Measurements for Test No. 440592-2.

D.2. SEQUENTIAL PHOTOGRAPHS

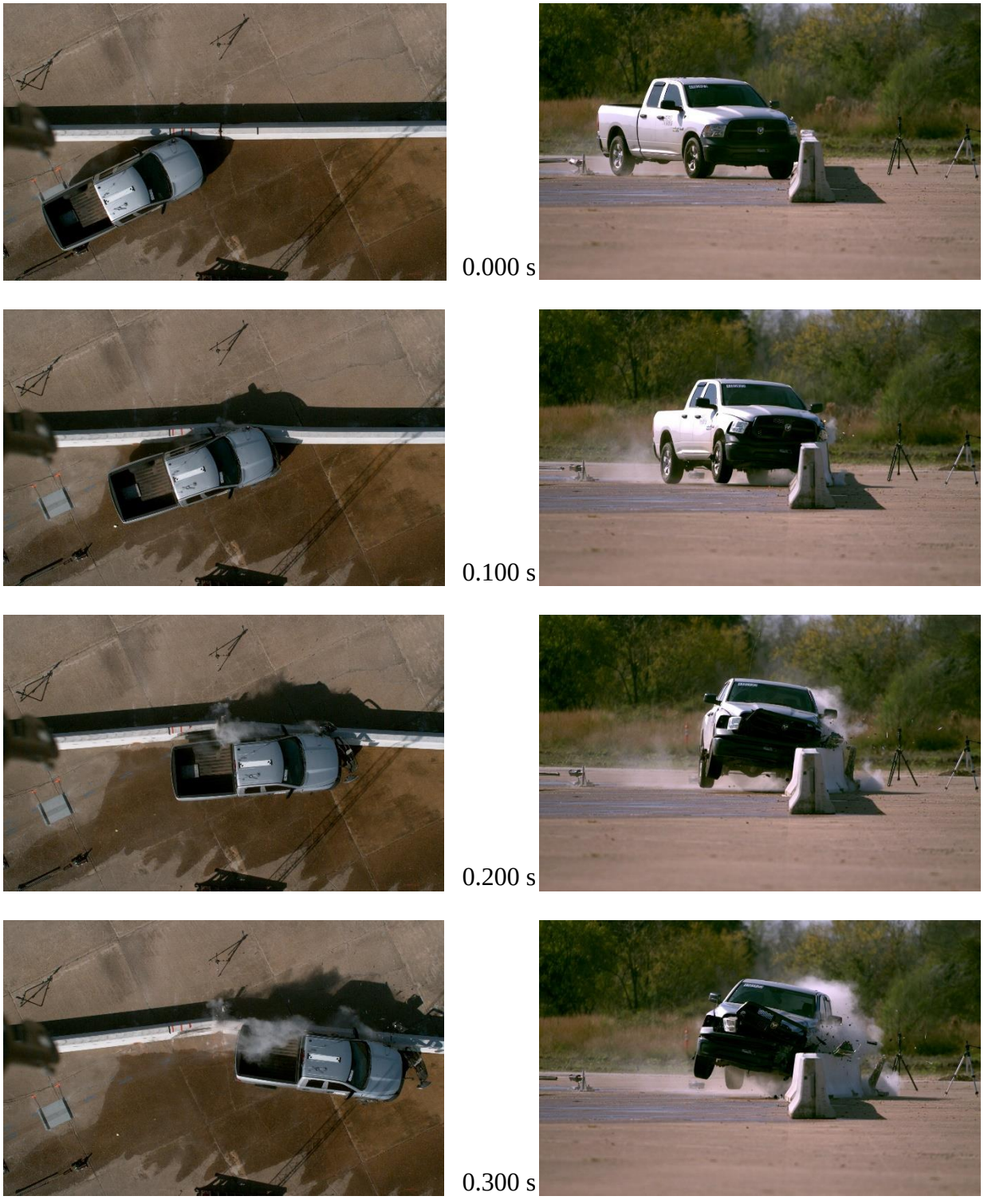


Figure D.4. Sequential Photographs for Test No. 440592-2 (Overhead and Frontal Views).


0.400 s



0.500 s



0.600 s



0.700 s


Figure D.4. Sequential Photographs for Test No. 440592-2 (Overhead and Frontal Views) (Continued).

0.000 s

0.400 s

0.100 s

0.500 s

0.200 s

0.600 s

0.300 s

0.700 s

Figure D.5. Sequential Photographs for Test No. 440592-2 (Rear View).

D.3. VEHICLE ANGULAR DISPLACEMENTS

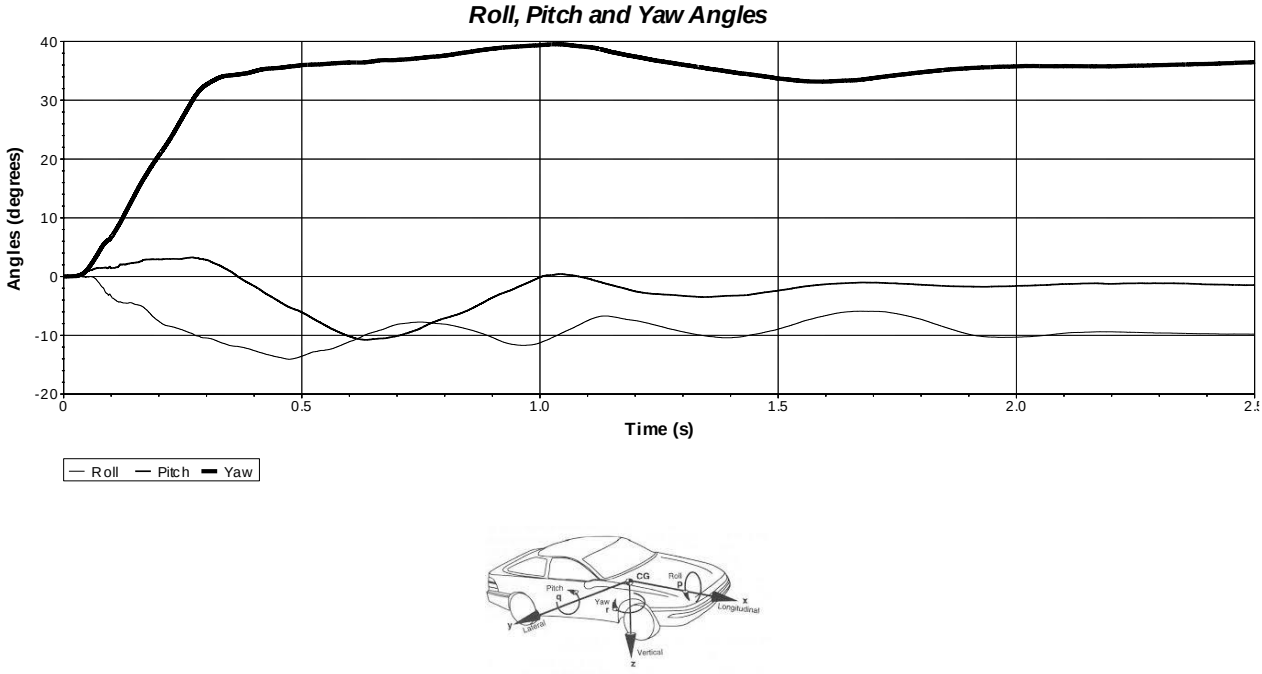


Figure D.6. Vehicle Angular Displacements for Test No. 440592-2.

D.4. VEHICLE ACCELERATIONS

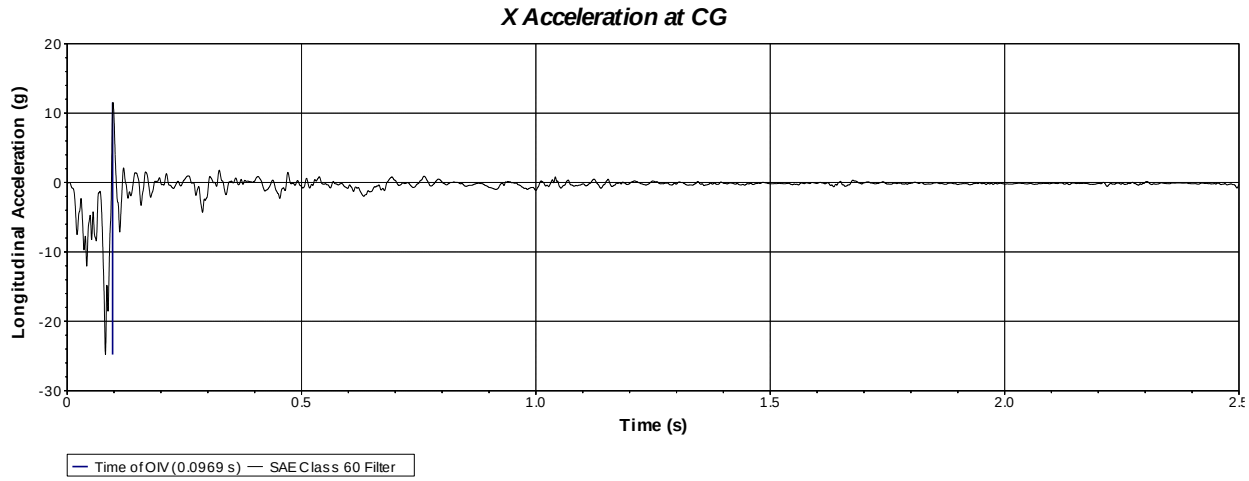


Figure D.7. Vehicle Longitudinal Accelerometer Trace for Test No. 440592-2 (Accelerometer Located at Center of Gravity).

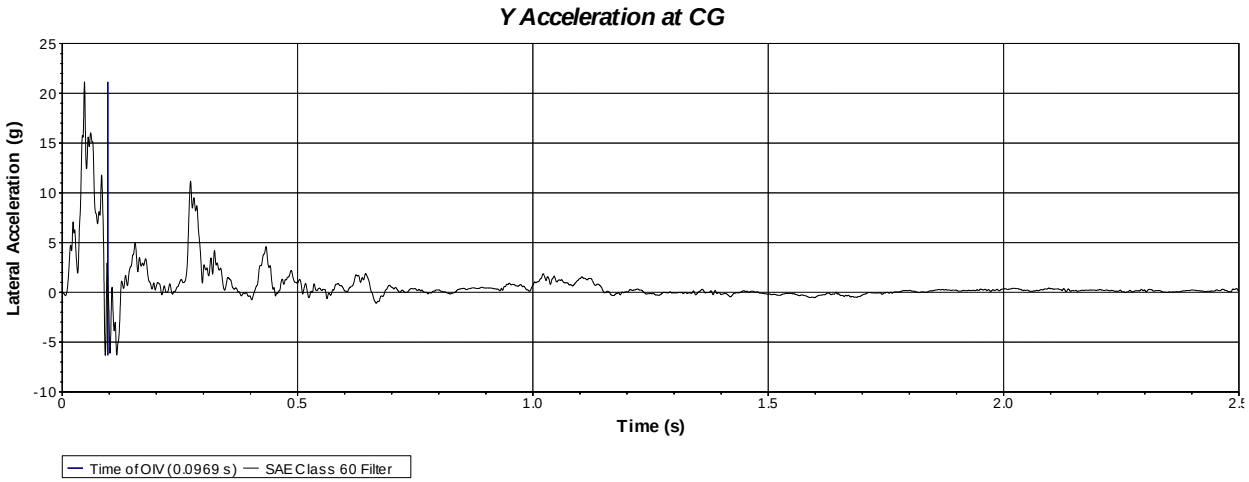


Figure D.8. Vehicle Lateral Accelerometer Trace for Test No. 440592-2 (Accelerometer Located at Center of Gravity).

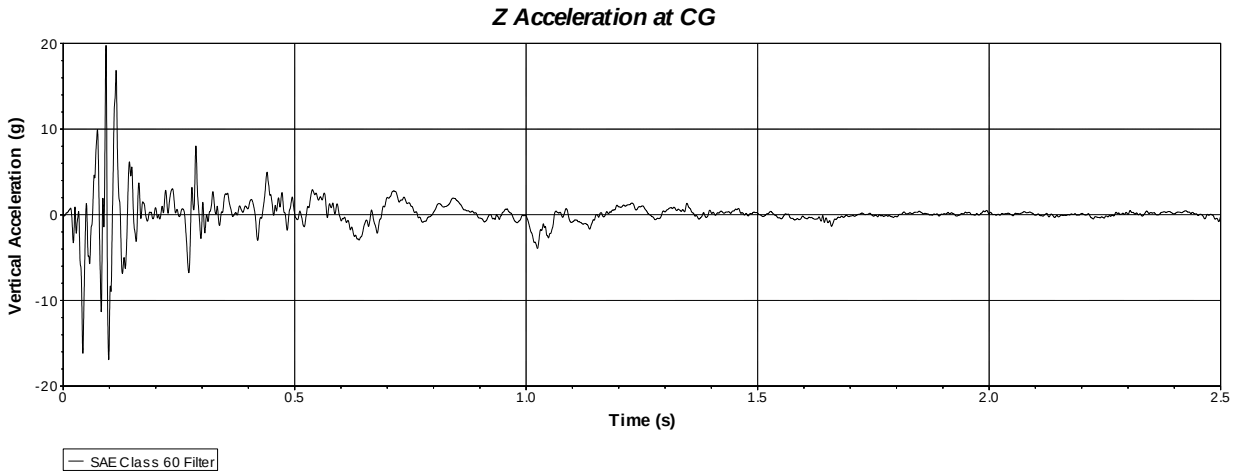


Figure D.9. Vehicle Vertical Accelerometer Trace for Test No. 440592-2 (Accelerometer Located at Center of Gravity).